27 W, 12 V and 5 V SMPS reference board with CoolSET™ ICE5QR1680BG-1

REF_5QR1680BG-1_27W1

About this document

Scope and purpose

This document describes a universal input 27 W, 12 V and 5 V offline flyback converter using the CoolSET™ 5th Generation Quasi-Resonant (QR) Plus ICE5QR1680BG-1 from Infineon, which offers high efficiency, low standby power with selectable entry and exit standby power options, a wider V_{CC} operating range with fast startup, robust line protection with input OVP and brownout, and various modes of protection for a highly reliable system.

This reference board is designed to evaluate the performance of CoolSET™ 5th Generation QR Plus ICE5QR1680BG-1 and its ease of use.

Intended audience

This document is intended for power supply design/application engineers, students, etc., who wish to design a low-cost and highly reliable offline SMPS as either auxiliary power supply for white goods, PCs, servers and TVs, or enclosed adapters for gaming consoles.

CoolSET™

Infineon's CoolSET™ AC-DC integrated power stages in quasi-resonant switching scheme offers increased robustness and outstanding performance. This family offers superior energy efficiency, comprehensive protective features, and reduced system costs and is ideally suited for auxiliary power supply applications in a wide variety of potential applications such as:

- SMPS
- Home appliances
- Server
- Telecom

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1 Introduction

This document describes a 27 W, 12 V and 5 V reference board designed in a quasi-resonant flyback converter topology using the CoolSET™ 5th Generation QR Plus ICE5QR1680BG-1 IC.

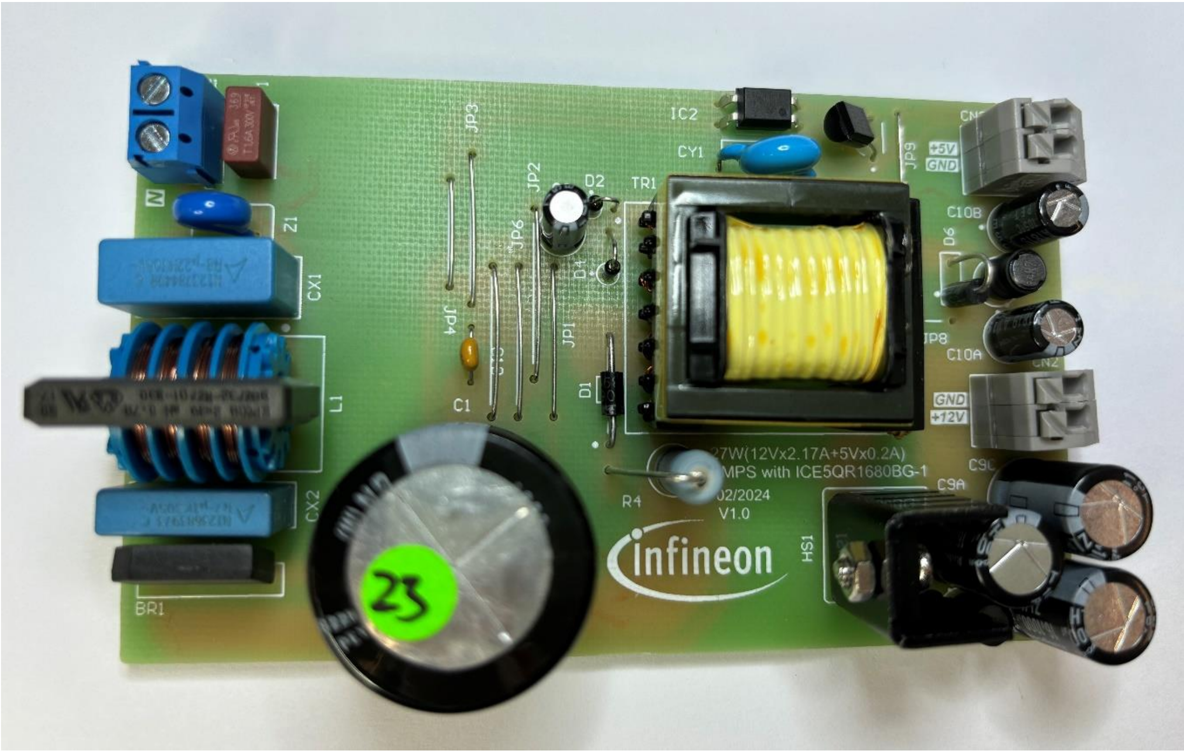
With the CoolMOS™ integrated in this IC, it simplifies the design and layout of the PCB. The new improved digital frequency reduction with proprietary QR operation offers lower EMI and higher efficiency for a wide AC range by reducing the switching frequency difference between low- and high-line. The active burst mode (ABM) power enables flexibility in standby power operation range selection and QR operation during ABM. As a result, the system efficiency over the entire load range is significantly improved compared to a conventional free-running QR converter implemented with only maximum switching frequency limitation at light loads.

In addition, several adjustable protection functions have been implemented in ICE5QR1680BG-1 to protect the system and customize the IC for the chosen application. In case of failure modes, like brownout or line overvoltage, V_{CC} overvoltage and undervoltage, open control loop or overload, output overvoltage, overtemperature, V_{CC} short-to-ground, the device enters protection mode.

By means of the cycle-by-cycle peak current limitation (PCL), the dimensions of the transformer and the current rating of the secondary diode can both be optimized. Thus, a cost-effective solution can easily be achieved. The target applications of ICE5QR1680BG-1 are portable gaming controllers and auxiliary power supplies for of white goods, PCs, printers, TVs, home theater/audio systems, etc.

This document contains the list of features, the power supply specifications, schematics, bill of materials (BOM), and the transformer construction documentation. Typical operating characteristics such as performance curve and scope waveforms are shown at the end of the document.

2 Reference board



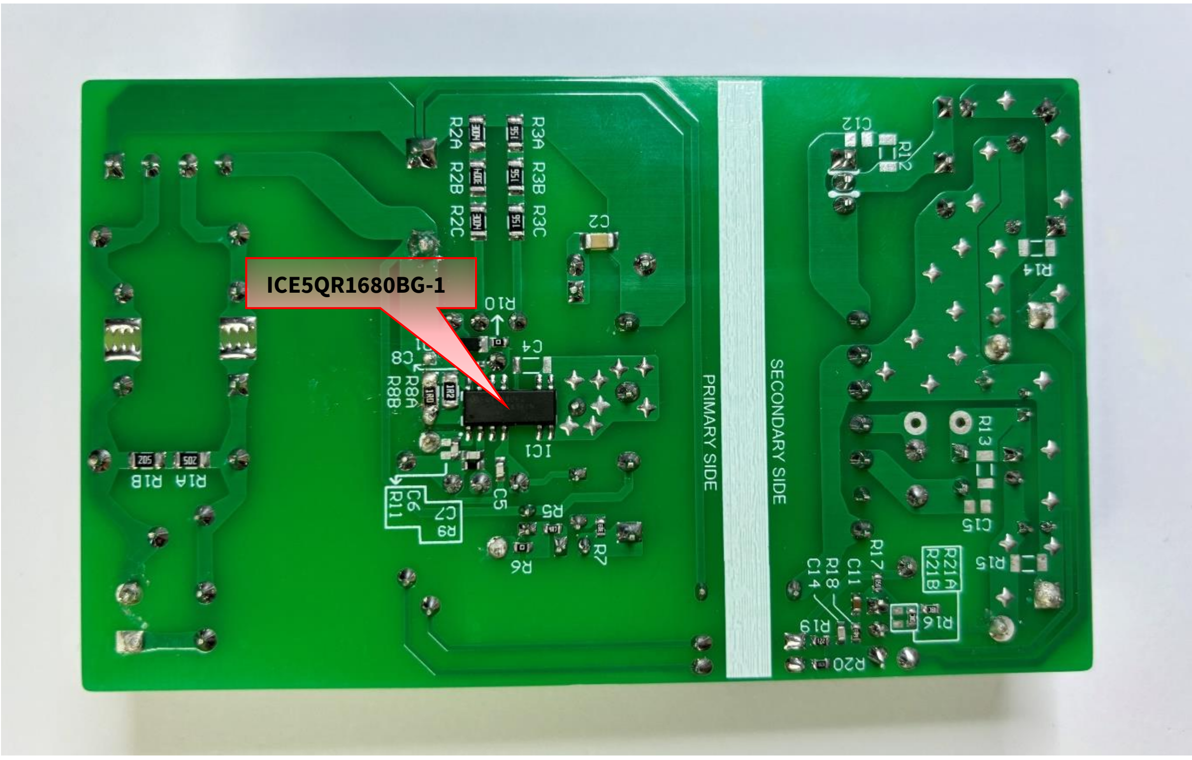


Figure 1 REF_5QR1680BG-1_27W1

3 Reference board specifications

Table 1 REF_5QR1680BG-1_27W1 specifications

Input voltage and frequency	85 V AC (60 Hz) ~300 V AC (50 Hz)
Output voltage, current, and power	(12 V x 2.17 A) + (5 V x 0.2 A) = 27 W
Regulation	+5 V: < ±5% +12 V: < ±10%
Output ripple voltage (full load, 85 V AC ~ 300 V AC)	5 $V_{ripple\_p\_p}$ < 100 mV 12 $V_{ripple\_p\_p}$ < 200 mV
Active mode four-point average efficiency (25%, 50%, 75%, 100% load)	> 83% at 115 V AC and 230 V AC
No-load power consumption	< 100 mW at 230 V AC
Conducted emissions (EN 55022 Class B)	Pass with 10 dB margin for 115 V AC and 6 dB margin for 230 V AC
ESD immunity (EN 61000-4-2)	Special level (±14 kV for contact and ±14 kV air discharge)
Surge immunity (EN 61000-4-5)	Installation Class 4 (±2 kV for line-to-line and ±4 kV for line-to-earth)
Form factor case size (L x W x H)	(110 x 66 x 27) mm^3

Note that the reference board is designed for dual-output with cross-regulated loop feedback. It may not regulate properly if loading is applied only to a single output. If you want to evaluate for single output (12 V only) conditions, make the following changes on the board:

1. Remove D6, L3, C10A, C10B, R16 to disable the 5 V output.
2. Change R21A to 10 kΩ and R17 to 38 kΩ to disable 5 V feedback and enable 100% weighted factor on 12 V output.

Because the board (especially the transformer) is designed for dual output with optimized cross regulation, single output efficiency might not be optimized. This configuration is only for IC functional evaluation under single output conditions.

4 Schematic

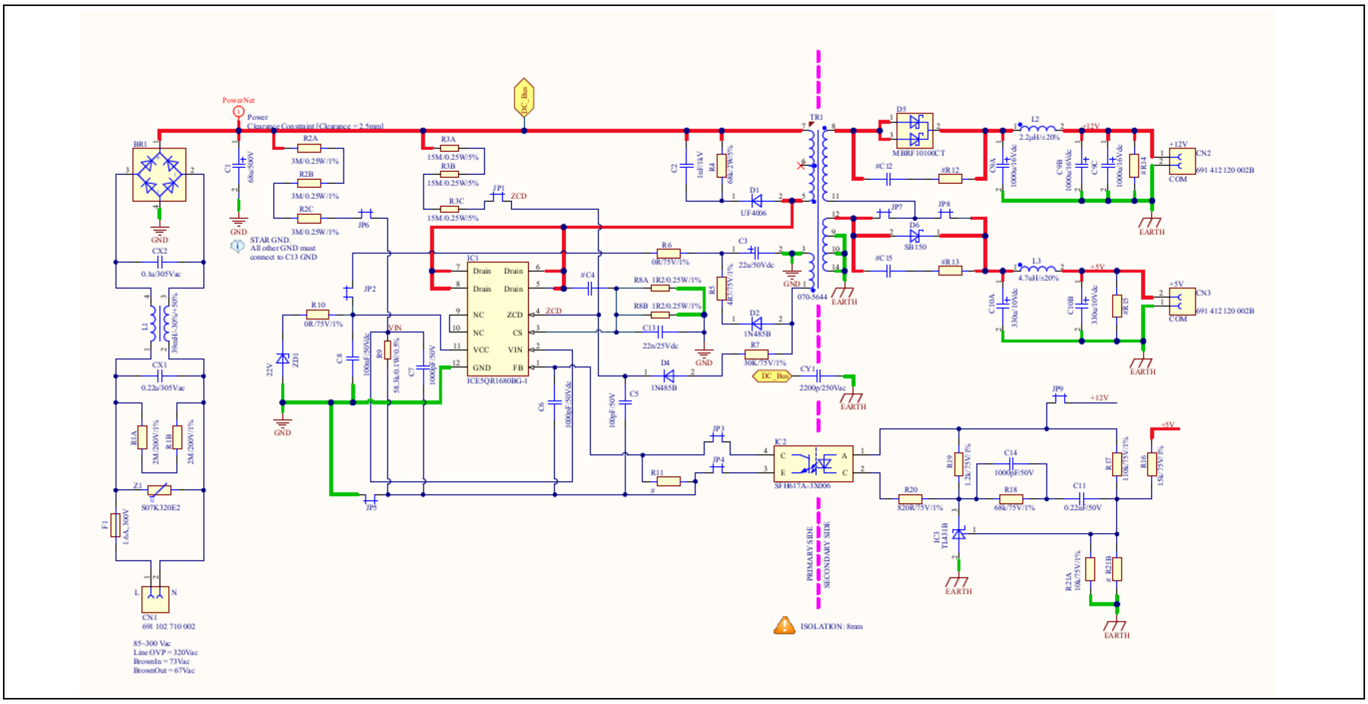


Figure 2 Schematic of REF_5QR1680BG-1_27W1

4.1 General guidelines for PCB layout

1. **Star ground at the bulk capacitor (C1):** Connect all primary grounds separately to the ground of bulk capacitor (C1) at one point. This reduces the switching noise going into the sensitive pins of the CoolSET™ device effectively. The primary star ground can be split into four groups as follows:
   - Combine the signal (all small signal grounds connecting to the CoolSET™ GND pin, such as filter capacitor grounds C6, C7, C8 and optocoupler ground) and power grounds (CS resistors R8A and R8B).
   - V_{CC} ground includes the V_{CC} capacitor ground (C3) and the auxiliary winding ground (pin 3) of the power transformer.
   - EMI return ground includes Y capacitor (CY1).
   - DC ground from bridge rectifier (BR1).
2. **Filter capacitor close to the controller ground:** Place the filter capacitors (C6, C7, and C8) close to the controller ground and the controller pin to reduce the switching noise coupled into the controller.
3. **HV traces clearance:** To avoid arcing, space out the high-voltage traces far apart from the nearby traces.
   - **400 V traces (positive rail of bulk capacitor C1) to nearby trace:** > 2.0 mm
   - **600 V traces (drain voltage of CoolSET™ IC1) to nearby trace:** > 2.5 mm
4. For better thermal performance, add a minimum copper area of 232 mm^2 at the drain pin on the PCB.
5. To minimize the switching emissions, keep the following as small as possible:
   - Power-loop area (bulk capacitor C1)
   - Primary winding of the transformer TR1 (pins 7 and 5)
   - IC1 drain pin
   - IC1 CS pin
   - CS resistor R8A/R8B)

5 Bill of materials

Table 2 Bill of materials

No.	Designator	Description	Part number	Manufacturer	Quantity
1	BR1	600 V/1 A	S1VBA60	Shindengen	1
2	CX1	0.22 µF/305 V	B32922C3224	Epcos	1
3	CY1	2.2 nF/500 V	DE1E3RA222MA4BQ	Murata	1
4	C1	68 µF/500 V	LGN2H680MELA25	Nichicon	1
5	CX2	0.1 µF/305 V	B329221C3104K	Epcos	1
6	C2	1 nF/1000 V	GRM31BR73A102KW01#	Murata	1
7	C3	22 µF/50 V	50PX22MEFC5X11	Rubycon	1
8	C8	100 nF/50 V	GRM188R71H104KA93D	Murata	1
9	C6, C7, C14	1 nF/50 V	GRM1885C1H102GA01D	Murata	3
10	C5	100 pF/50 V	GRM1885C1H101GA01D	Murata	1
11	C9A, C9B, C9C	1000 uF/16 V	16ZLH1000MEFC10X16	Rubycon	3
12	C10A, C10B	330 uF/10 V	10ZLH330MEFC6.3X11	Rubycon	2
13	C11	220 nF/50 V	GRM188R71H224KAC4D	Murata	1
14	C13	22 nF/25 V	K223K15X7RF5UL2	Murata	1
15	D1	1 A/800 V	UF4006	–	1
16	D2,D4	0.2 A/200 V	1N485B	–	2
17	D5	10 A/100 V	MBRF10100CT	Vishay	1
18	D6	1 A/45 V	SB150	Vishay	1
19	F1	1.6 A/300 V	36911600000	Littlefuse	1
20	HS1	Heatsink	577202B00000G	AAVID	1
21	IC1	ICE5QR1680BG-1	ICE5QR1680BG-1	Infineon	1
22	IC2	Optocoupler	SFH617A-3	–	1
23	IC3	Shunt regulator	TL431BVLPG	–	1
24	JP1,JP2,JP3,JP4, JP5,JP6,JP7,JP9	Jumper	–	–	8
25	L1	39 mH/0.7 A	B82732R2701B030	Epcos	1
26	L2	2.2 uH/6.3A	744 746 202 2	Würth Elektronik	1
27	L3	4.7 uH/4.2 A	744 746 204 7	Würth Elektronik	1
28	R1A, R1B	2 MΩ/5%/200 V	RC1206JR-072ML	–	2
29	R2A, R2B, R2C	3 MΩ/0.25 W/1%	RC1206FR-073ML	–	3
30	R3A, R3B, R3C	15 MΩ/0.25 W/5%	RC1206JR-0715ML	–	3
31	R4	68 kΩ/2 W/500 V	MO2CT631R683J	KOA Speer	1
32	R5	4.7 Ω (0603)	–	–	1
33	R6, R10	0 Ω (0603)	–	–	2

No.	Designator	Description	Part number	Manufacturer	Quantity
34	R7	30 kΩ/±1% (0603)	–	–	1
35	R8A, R8B	1.2 R/0.25 W/±1%	–	–	2
36	R9	58.3 kR/0.1 W/0.5%	RT0603DRE0758K3L	–	1
37	R16	15 kΩ (0603)	–	–	1
38	R17	110 kΩ (0603)	–	–	1
39	R18	68 kΩ (0603)	–	–	1
40	R19	1.2 kΩ (0603)	–	–	1
41	R20	820 Ω (0603)	–	–	1
42	R21A	10 kΩ (0603)	–	–	1
43	TR1	400 µH	750343389 (Rev 0.0)	Würth Elektronik	1
44	Z1	Varistor	B72207S2321K101	Epcos	1
45	ZD1	22 V Zener	MMSZ5251B-7-F	Diodes Incorporated	1
46	CN1 (L N)	Connector	691102710002	Würth Elektronik	1
47	CN2 (+12 V com), CN3 (+5 V com)	Connector	691 412 120 002B	Würth Elektronik	2

6 Circuit description

6.1 Line input

The AC line input side comprises the input fuse (F1) as overcurrent protection. The choke (L1), X-capacitors (CX1 and CX2), and Y-capacitor (CY1) act as EMI suppressors. The sparking gap and varistor (Z1) absorb the high-voltage stress during a lightning surge test. A rectified DC voltage (120~424 V DC) is obtained through the bridge rectifier (BR1) together with the bulk capacitor (C1).

6.2 Startup

To achieve fast and safe startup, ICE5QR1680BG-1 is implemented with startup resistors and V_{CC}-to-GND short-circuit protection. When V_{VCC} reaches the turn-on voltage threshold (16 V), the IC begins with a soft start.

The soft start implemented in ICE5QR1680BG-1 is a digital time-based function. The preset soft-start time is 12 ms with four steps. If not limited by other functions, the peak voltage on the CS pin will increase incrementally from 0.3 V to 1 V. After the IC turns on, the V_{CC} voltage is supplied by auxiliary windings of the transformer. V_{CC} short-to-GND short-circuit protection is implemented during the startup time.

6.3 Integrated CoolMOS™ MOSFET and PWM control

ICE5QR1680BG-1 comprises a power MOSFET and the proprietary novel QR controller, which enables higher average efficiency and low EMI. This integrated solution simplifies the circuit layout and reduces the cost of PCB manufacturing. The PWM switch-on is determined by the zero-crossing detection input signal and the value of the up/down counter. The PWM switch-off is determined by the feedback signal VFB and the current sensing signal VCS. ICE5QR1680BG-1 also performs all the necessary protection functions in the flyback converters. For more details, refer to the datasheet [1].

6.4 RCD clamper circuit

A clamper network (R4, C2, and D1) dissipates the energy of the leakage inductance and suppresses the ringing on the SMPS transformer.

6.5 Output stage

There are two outputs on the secondary side (12 V and 5 V). The power is coupled out via the Schottky diodes (D5 and D6). The capacitors (C9A and C10A) provide energy buffering followed by the L-C filters (L2-C9B, C9C, and L3-C10B) to reduce the output ripple and prevent interference between the SMPS switching frequency and line frequency. Storage capacitors (C9A and C10A) are designed to have the smallest possible internal resistance (ESR) to minimize the output voltage ripple caused by the triangular current.

6.6 Feedback loop

For feedback, the output is sensed by the voltage divider (R16, R17, R21A, and R21B) and compared to the IC3 (TL431) internal reference voltage. C11, C14, and R18 comprise the compensation network. The output voltage of IC3 (TL431) is converted to the current signal via the optocoupler (IC2) and two resistors (R19 and R20) for regulation control.

6.7 Primary-side peak current control

The MOSFET drain-source current is sensed via external resistors (R8A and R8B). Because ICE5QR1680BG-1 is a current mode controller, it would have a cycle-by-cycle primary current and feedback voltage control, which ensures that the converter's maximum power is controlled in every switching cycle.

For a QR flyback converter, the maximum possible output power is increased when a constant current limit value is used for the entire line input voltage range. However, this is not desirable because this will increase the cost of the transformer and output diode in case of output over-power conditions.

Internal current limitation with line-dependent V_{CS} curve and the new proprietary QR switching, which reduces the switching frequency difference between the minimum and maximum line are implemented in ICE5QR1680BG-1. As a result, the maximum output power can be limited against the input voltage.

6.8 Digital frequency reduction

During normal operation, the switching frequency for ICE5QR1680BG-1 is digitally reduced with decreasing load. At light load conditions, the MOSFET will be turned on – not at the first minimum drain-source voltage time, but on the n^{th}. The counter is within a range of 1 to 8 for low-line and 3 to 10 for high-line, which depends on the feedback voltage in a time base. The feedback voltage decreases when the output power requirement decreases, and vice versa. Therefore, the counter is set by the monitoring voltage (V_{FB}). The counter will be increased with low V_{FB} and decreased with high V_{FB}. The thresholds are preset inside the IC.

6.9 Active burst mode (ABM)

ABM entry and exit power (two levels) can be selected in ICE5QR1680BG-1 [1]. At light load conditions, the SMPS enters into ABM with QR switching. At this stage, the controller is always active but the V_{VCC} must be kept above the switch-off threshold. During ABM, the efficiency increases significantly; and it supports low ripple on V_{out} and fast response on load jump.

For determination of entering ABM operation, three conditions apply:

- The feedback voltage is lower than the threshold of V_{FBEB}.
- The up/down counter is 8 for low-line and 10 for high-line.
- A certain blanking time (t_{BEB} = 20 ms) is required.

Once all of these conditions are fulfilled, the ABM flip-flop is set and the controller enters ABM operation. This multi-condition determination for entering ABM operation prevents mis-triggering of ABM, so that the controller enters ABM operation only when the output power is really low during the preset blanking time.

During ABM, the maximum CS voltage is reduced from 1 V to 0.31/0.35 V to reduce the conduction loss and the audible noise. In ABM operation, the feedback voltage changes like a sawtooth between 2 V and 2.4 V.

The feedback voltage immediately increases if there is a sudden increment in the output load, as observed by one comparator. As the current limit is 31/35% during ABM a certain load is needed so that the feedback voltage can exceed V_{FBLB} (2.75 V). After leaving ABM, maximum current can now be provided to stabilize V_{out}. In addition, the up/down counter will be set to '1' (low-line) or '3' (high-line) immediately after leaving ABM. This is helpful to decrease the output voltage undershoot.

7 Protection features

ICE5QR1680BG-1 provides comprehensive protection to ensure that the system is operating safely. When the faults are detected, the system enters the protection mode, and remains in this mode until the fault is removed, and then the system resumes normal operation. Table 3 lists the protections and failure conditions.

Table 3 Protection functions of ICE5QR1680BG-1

Protection function	Failure condition	Protection mode
Line overvoltage	$V_{VIN} > V_{VIN\_LOVP}$	Non-switch auto-restart
Brownout	$V_{VIN} < V_{VIN\_BO}$	Non-switch auto-restart
V_{CC} overvoltage	$V_{VCC} > V_{VCC\_OVP}$	Odd-skip auto-restart
V_{CC} undervoltage	$V_{VCC} < V_{VCC\_OFF}$	Auto-restart
Overload	$V_{FB} > V_{FB\_OLP}$ and lasts for 30 ms	Odd-skip auto-restart
Output overvoltage	$V_{ZCD} > V_{ZCD\_OVP}$ and lasts for 10 consecutive pulses	Odd-skip auto-restart
Overtemperature (junction temperature of controller chip only)	T_J > 140°C with 40°C hysteresis to reset	Non-switch auto-restart
V_{CC} short-to-GND (V_{VCC} = 0 V, $R_{StartUp}$ = 50 MΩ and V_{Drain} = 90 V)	$V_{VCC} < V_{VCC\_SCP}$, $I_{VCC\_Charge} = I_{VCC\_Charge1}$	Cannot start up

8 PCB layout

8.1 Top side

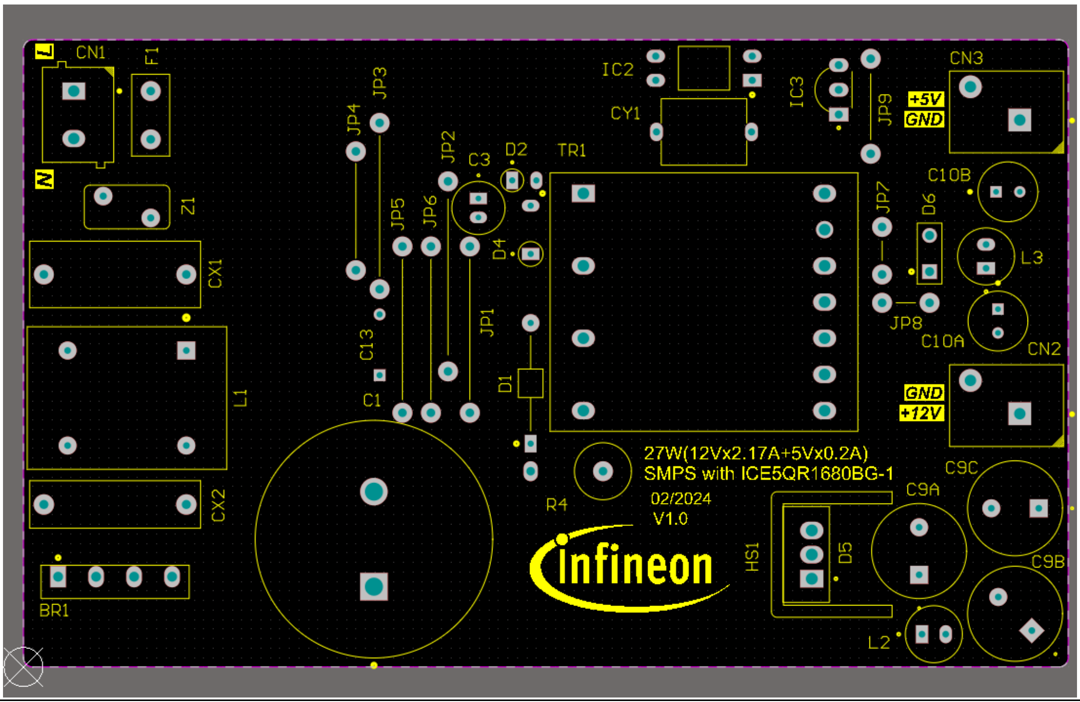


Figure 3 Top side component legend

8.2 Bottom side

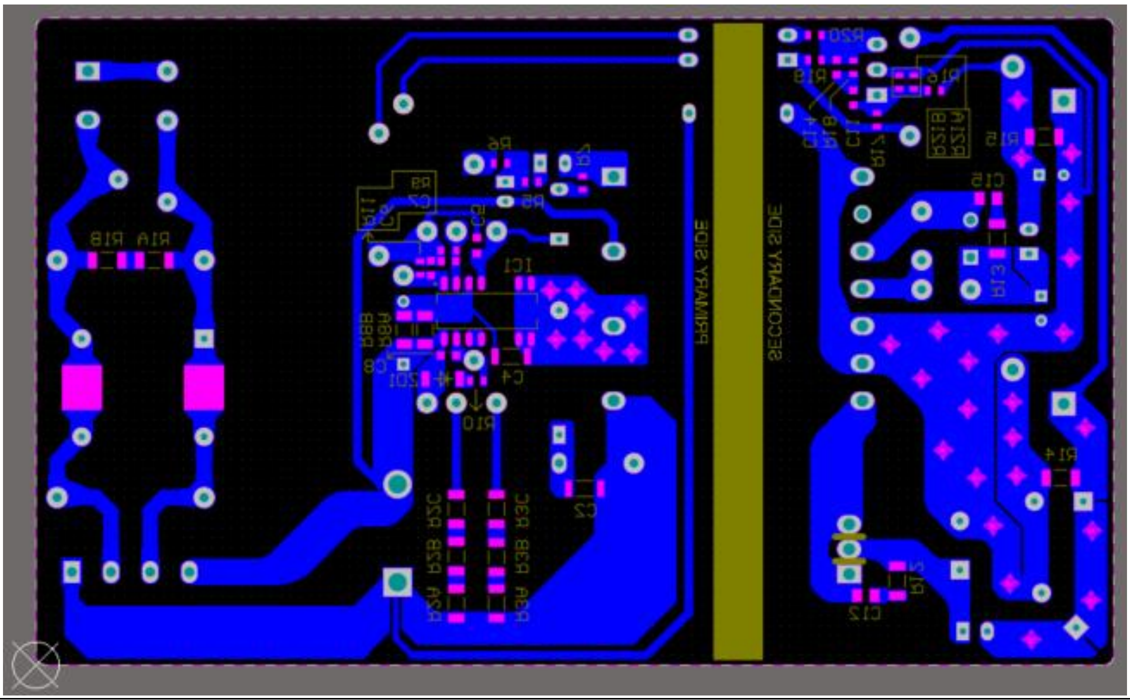
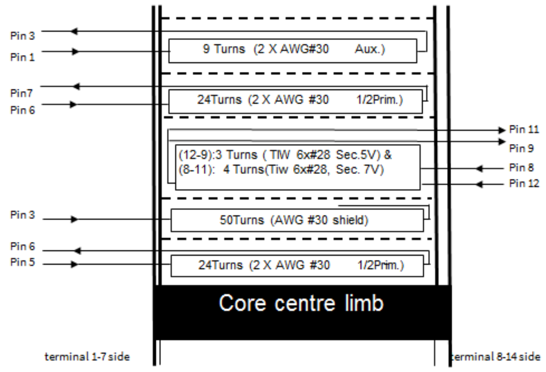


Figure 4 Bottom side copper and component legend

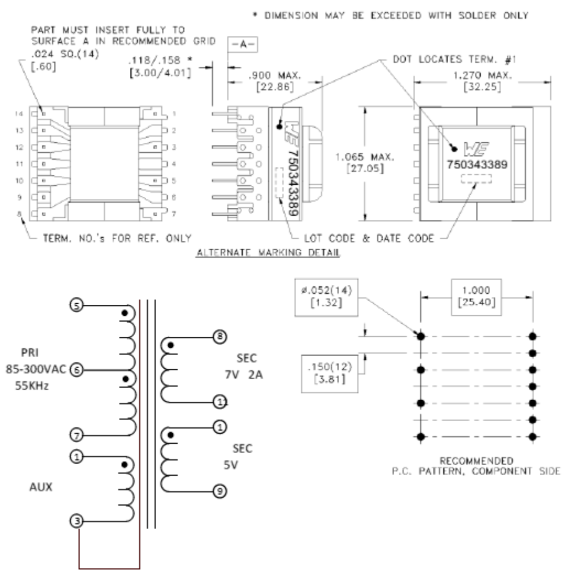
9 Transformer construction

- **Core and materials:** EE25/13/7(EF25), TP4A (TDG)
- **Bobbin:** 070-5644 (14-pin, THT, horizontal version)
- **Primary inductance:** Lp = 400 µH (±10%), measured between pin 5 and pin 7
- **Manufacturer and part number:** Würth Elektronik Midcom (750343389)



Start	Stop	No. of turns	Wire size	Layer
5	6	24	2XAWG30	1/2 Primary
3		50REF	AWG30	SHIELD
12	9	3	6XAWG28, Triple insulated wire	Sec, 5V
8	11	4	6XAWG28, Triple insulated wire	SEC, 7V
6	7	24	2XAWG30	1/2 Primary
1	3	9	2XAWG30	AUX

CUSTOMER TERMINAL	RoHS	LEAD(Pb)–FREE
Sn 96%, Ag 4%	Yes	Yes



ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER	TEST CONDITIONS	VALUE
D.C. RESISTANCE 1-3	@20°C	0.100 ohms max.
D.C. RESISTANCE 5-7	@20°C	0.422 ohms max.
D.C. RESISTANCE 8-11	@20°C	0.013 ohms max.
D.C. RESISTANCE 12-9	@20°C	0.010 ohms max.
INDUCTANCE 5-7	50kHz, 100mV, Ls	400.0µH ±10%
LEAKAGE INDUCTANCE 5-7	tie(1+3+8+9+11+12),100kHz, 100mV, Ls	7.0µH max.
DIELECTRIC 7-8	tie(3+5, 8+9), 3750VAC, 1 second	
DIELECTRIC 8-CORE	tie(8+9), 3750VAC, 1 second	
TURNS RATIO	(5-7):(1-3)	5.33:1, ±2%
TURNS RATIO	(5-7):(8-11)	12:1, ±2%
TURNS RATIO	(5-7):(12-9)	16:1, ±2%

GENERAL SPECIFICATIONS:

OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC60950-1,

- Reinforced insulation for a primary circuit at a working voltage of 300Vrms, Overvoltage Category II.

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.

DFM		Packaging Specifications Method: Tray PKG-0737	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03] This drawing is dual dimensioned. Dimensions in brackets are in millimeters.	DRAWING TITLE: TRANSFORMER
DATE				PART NO. 750343389
ENG	HZH			
REV.	00	CONVENTION PLACEMENT		
DATE	2016-10-06	www.we-online.com/midcom		SPECIFICATION SHEET 1 OF 1

Figure 5 Transformer structure

10 Test results

10.1 Efficiency, regulation, and output ripple

Table 4 Efficiency, regulation, and output ripple

Input (V AC/Hz)	P_{in} (W)	V_{out1} (V DC)	I_{out1} (A)	V_{out2} (V DC)	I_{out2} (A)	$V_{OutRPP1}$ (mV)	$V_{OutRPP2}$ (mV)	P_{out} (W)	Efficiency η (%)	Average η (%)	OLP P_{in} (W)	OLP I_{out12V} (fixed 5 V at 0.2 A) (A)
85 V AC/ 60 Hz	0.035	11.95	0.00	4.92	4.91	0.000	32				41.45	2.72
	0.079	12.90	0.00	4.79	4.81	0.006	83	0.03				
	7.930	11.92	0.54	4.93	4.94	0.050	14	6.68	84.28			
	14.470	11.86	1.00	4.94	4.94	0.060	16	12.16	84.01	83.29		
	15.930	11.92	1.08	4.93	4.94	0.100	16	13.37	83.91			
	24.170	11.92	1.63	4.93	4.93	0.150	16	20.17	83.45			
	32.930	11.92	2.17	4.93	4.93	0.200	21	26.85	81.54			
115 V AC/ 60 Hz	0.039	11.95	0.00	4.92	4.91	0.000	32		~~0.00~~		46.00	3.15
	0.087	12.92	0.00	4.79	4.80	0.006	90	0.03				
	7.921	11.92	0.54	4.93	4.98	0.050	18	6.68	84.37			
	14.295	11.85	1.00	4.94	4.94	0.060	16	12.15	84.97	84.54		
	15.737	11.91	1.08	4.93	4.93	0.100	16	13.36	84.87			
	23.780	11.91	1.63	4.93	4.93	0.150	16	20.15	84.75			
	31.845	11.90	2.17	4.93	4.93	0.200	16	26.81	84.19			
230 V AC/ 50 Hz	0.068	11.94	0.00	4.93	4.91	0.000	34				48.10	3.32
	0.123	12.98	0.00	4.78	4.80	0.006	85	0.03				
	8.123	11.92	0.54	4.93	4.93	0.050	14	6.68	82.28			
	14.468	11.86	1.00	4.94	4.94	0.060	16	12.16	84.02	83.97		
	15.860	11.92	1.08	4.93	4.93	0.100	16	13.37	84.28			
	23.840	11.91	1.63	4.93	4.93	0.150	16	20.15	84.53			
	31.640	11.91	2.17	4.93	4.93	0.200	16	26.83	84.80			
265 V AC/ 50 Hz	0.081	11.94	0.00	4.93	4.91	0.000	34		~~0.00~~		48.78	3.45
	0.132	12.99	0.00	4.78	4.80	0.006	90	0.03				
	8.260	11.93	0.54	4.93	4.94	0.050	18	6.69	80.98			
	14.550	11.86	1.00	4.94	4.94	0.060	14	12.16	83.55	83.40		
	15.980	11.92	1.08	4.93	4.93	0.100	14	13.37	83.65			
	23.920	11.92	1.63	4.93	4.93	0.150	16	20.17	84.32			
	31.700	11.91	2.17	4.93	4.93	0.200	18	26.83	84.64			
300 V AC/ 50 Hz	0.106	11.94	0.00	4.93	4.91	0.000	34				50.36	3.51
	0.156	13.00	0.00	4.78	4.80	0.006	93	0.03				
	8.440	11.92	0.54	4.93	4.94	0.050	14	6.68	79.19			
	14.710	11.86	1.00	4.94	4.94	0.060	16	12.16	82.64	82.30		
	16.130	11.91	1.08	4.93	4.94	0.100	16	13.36	82.80			
	24.210	11.91	1.63	4.93	4.93	0.150	16	20.15	83.24			
	31.920	11.90	2.17	4.93	4.93	0.200	16	26.81	83.99			

- **Minimum load condition:** 5 V at 6 mA
- **Typical load condition:** 5 V at 60 mA and 12 V at 1 A
- **Maximum load condition:** 5 V at 200 mA and 12 V at 2.17 A

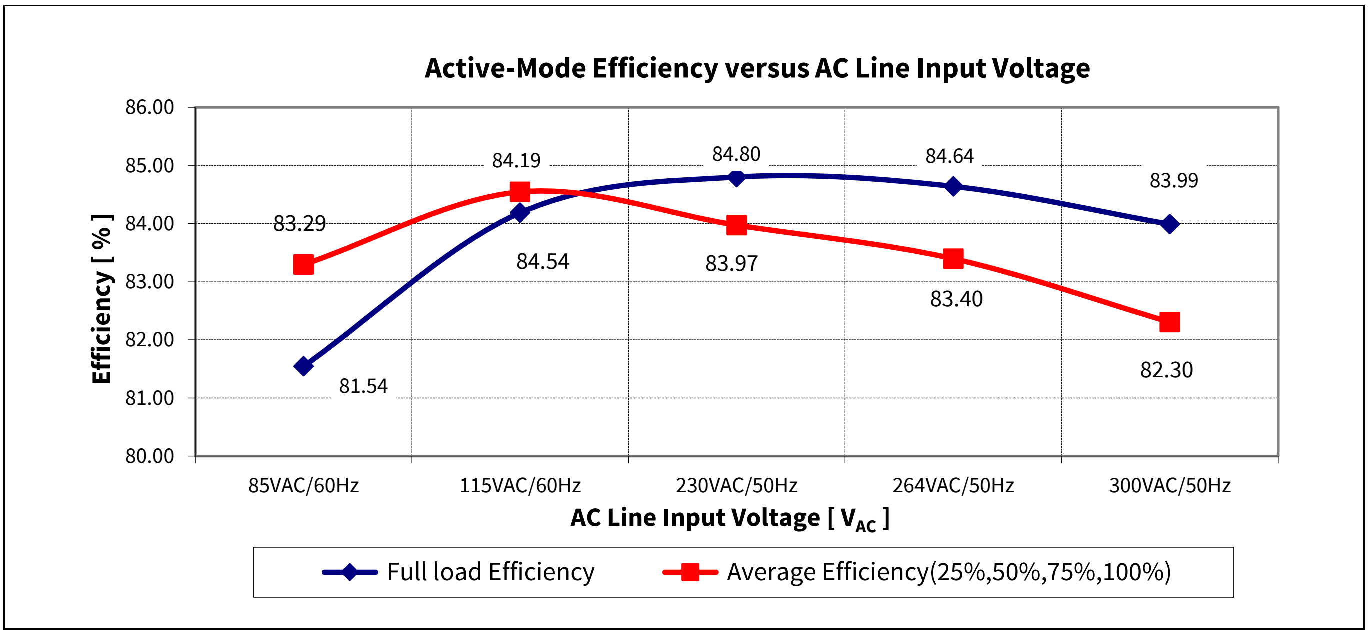


Figure 6 Efficiency vs. AC-line input voltage

10.2 Standby power

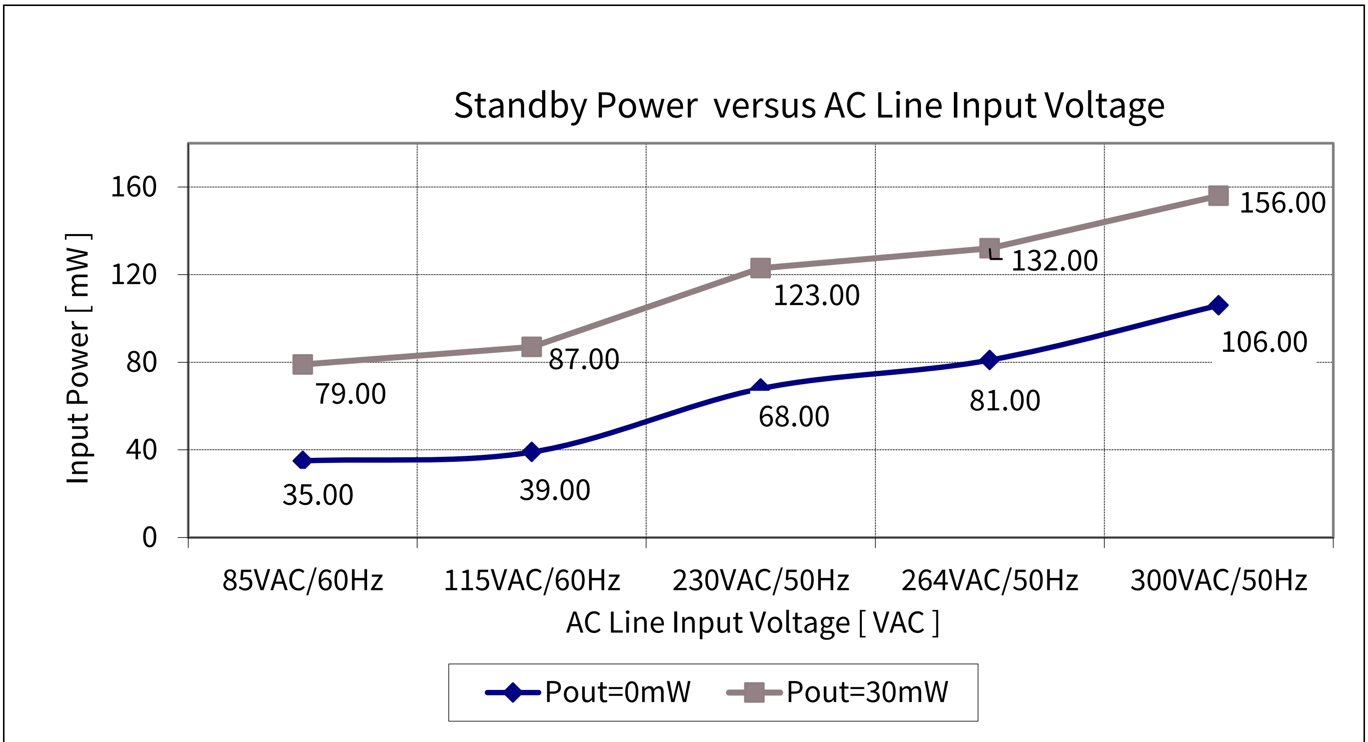


Figure 7 Standby power at no-load and 30 mW load vs. AC-line input voltage (measured by Yokogawa WT210 power meter – integration mode)

10.3 Line regulation

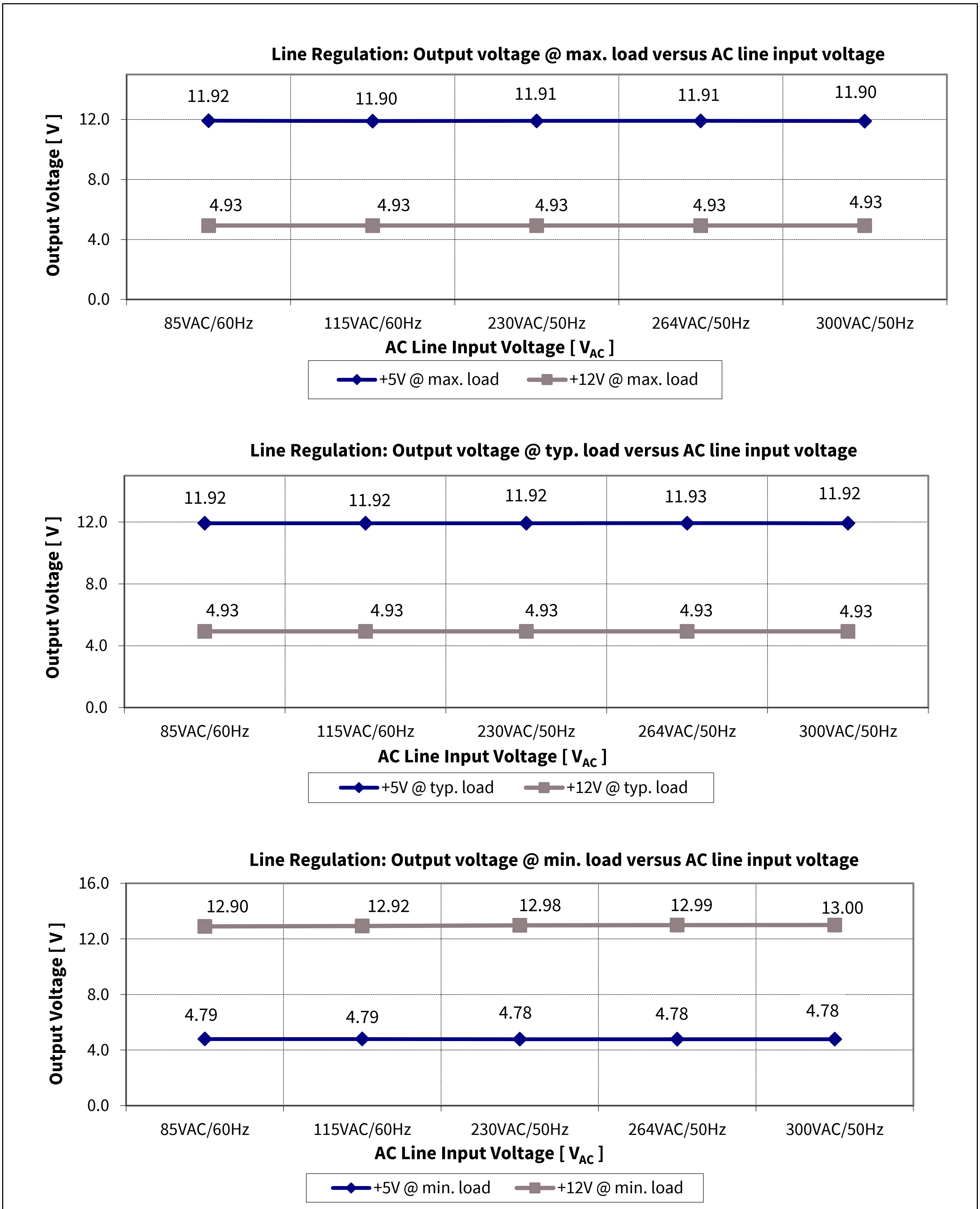


Figure 8 Line regulation V_{Out} at full load vs. AC-line input voltage

10.4 Load regulation

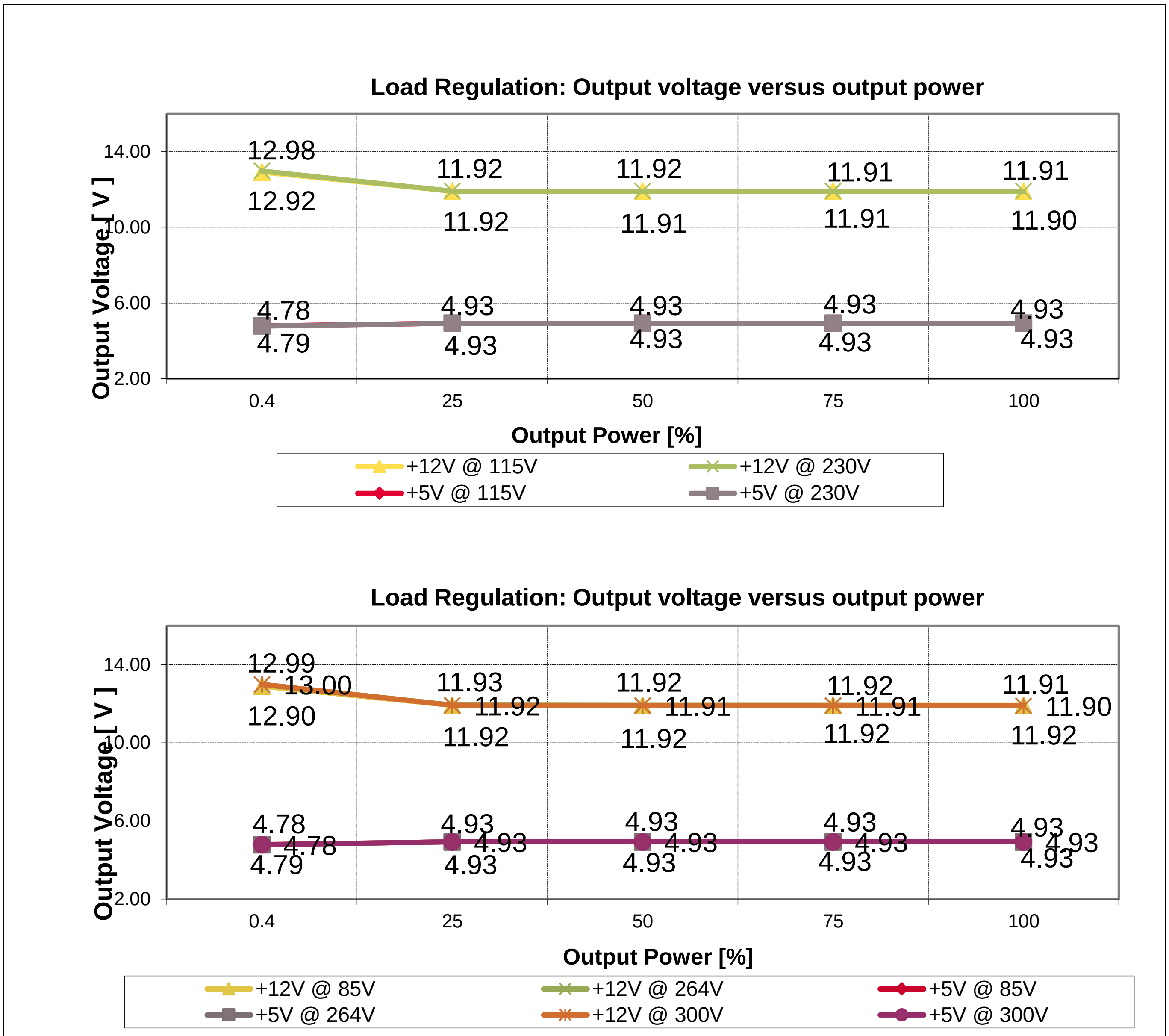


Figure 9 **Load regulation V_{Out} vs. output power**

10.5 Maximum input power

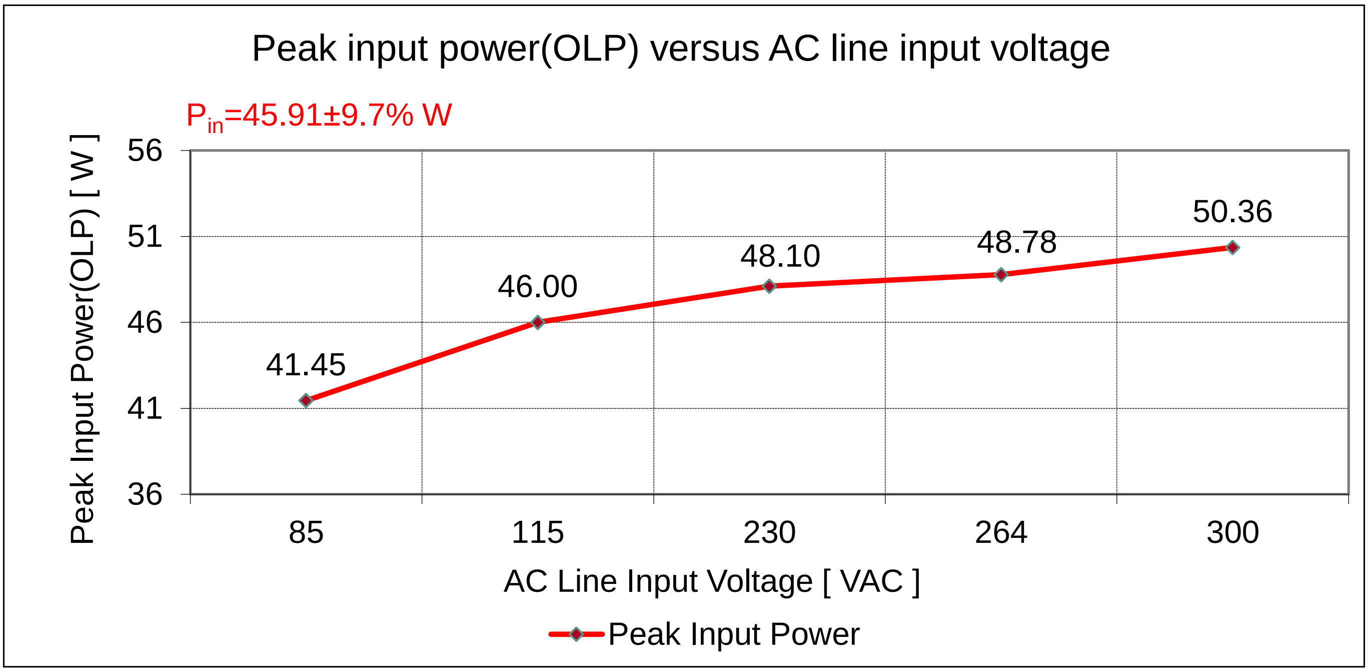


Figure 10 Maximum input power (before overload protection) vs. AC-line input voltage

10.6 ESD immunity (EN 61000-4-2)

Pass EN 61000-4-2 special level (±14 kV for contact discharge and ±16 kV air discharge).

10.7 Surge immunity (EN 61000-4-5)

Pass EN 61000-4-5 installation Class 4 (±2 kV for line-to-line and ±4 kV for line-to-earth).[1]

10.8 Conducted emissions (EN 55022 Class B)

The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) Class B. The reference board was set up at maximum load (27 W) with an input voltage of 115 V AC and 230 V AC.

[1] PCB spark-gap distance needs to reduce to 0.5 mm and C1 change to 120 µF.

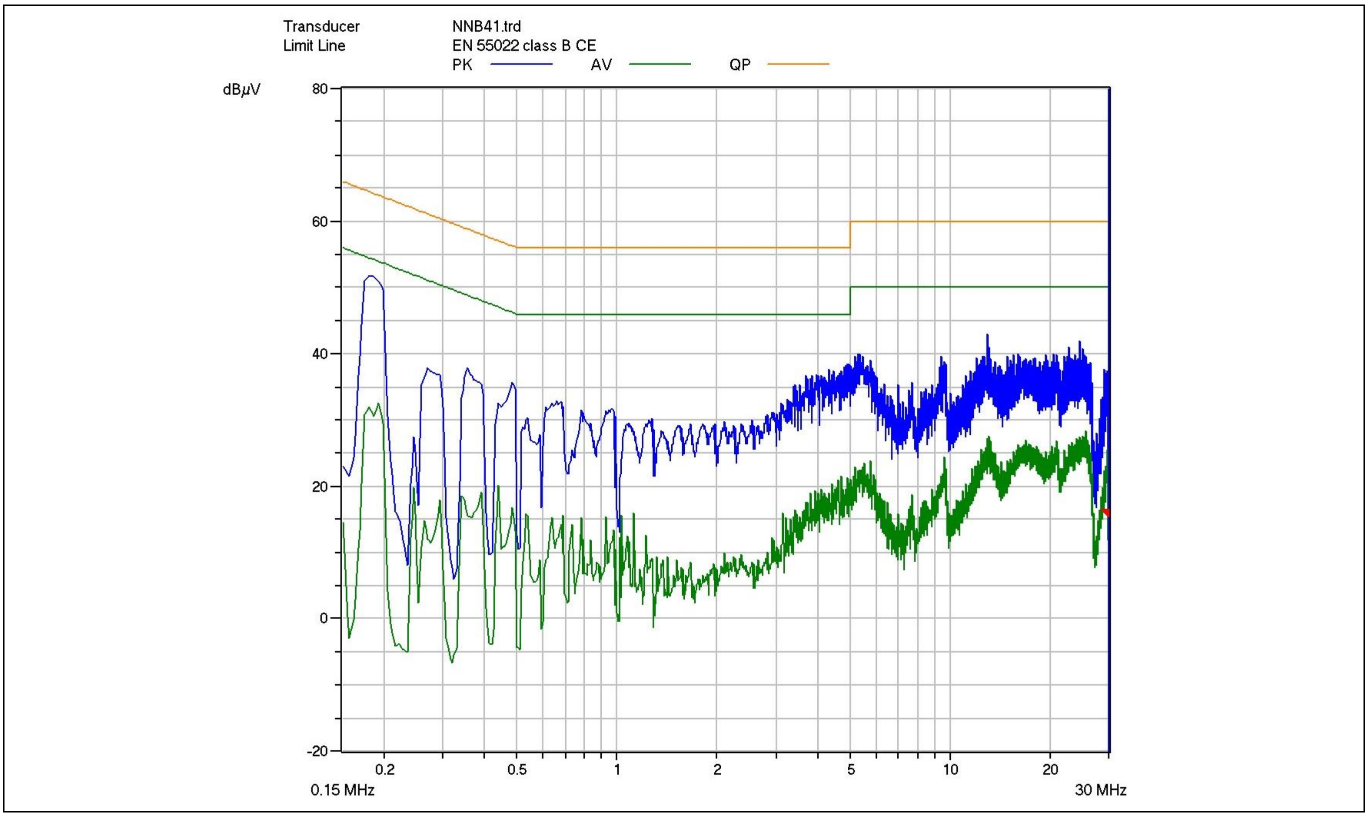


Figure 11 Conducted emissions (line) at 115 V AC and maximum load

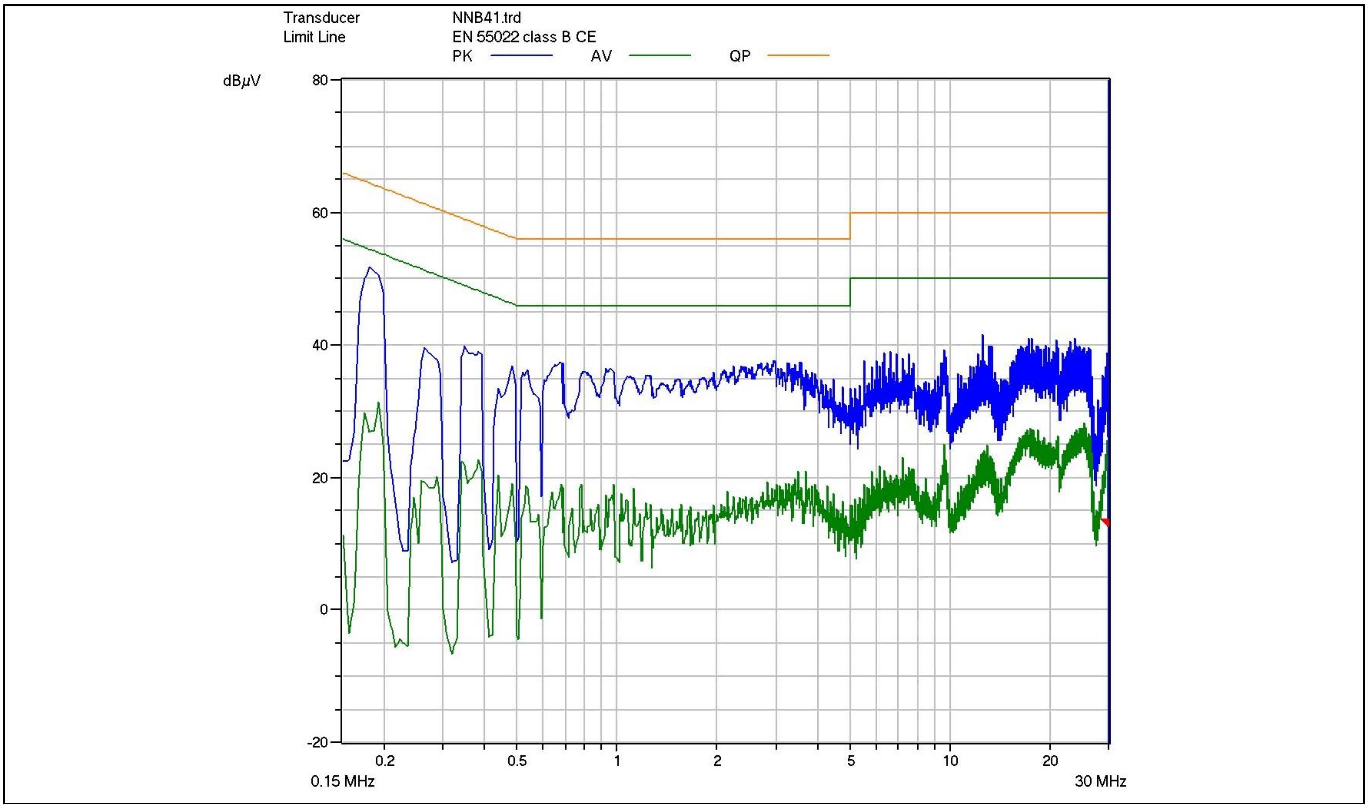


Figure 12 Conducted emissions (neutral) at 115 V AC and maximum load

Pass conducted emissions EN 55022 (CISPR 22) Class B with 10 dB margin for quasi-peak measurement at low-line (115 V AC).

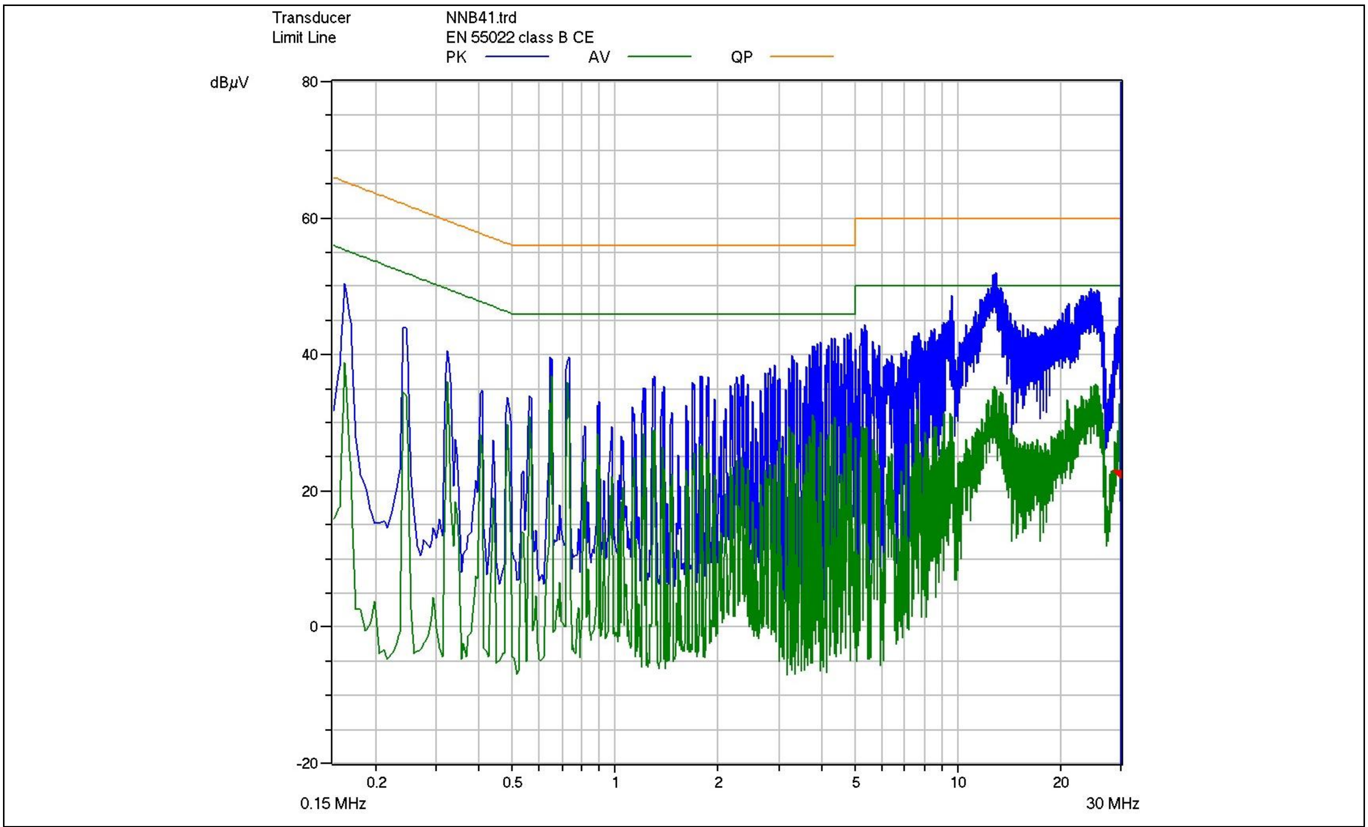


Figure 13 Conducted emissions (line) at 230 V AC and maximum load

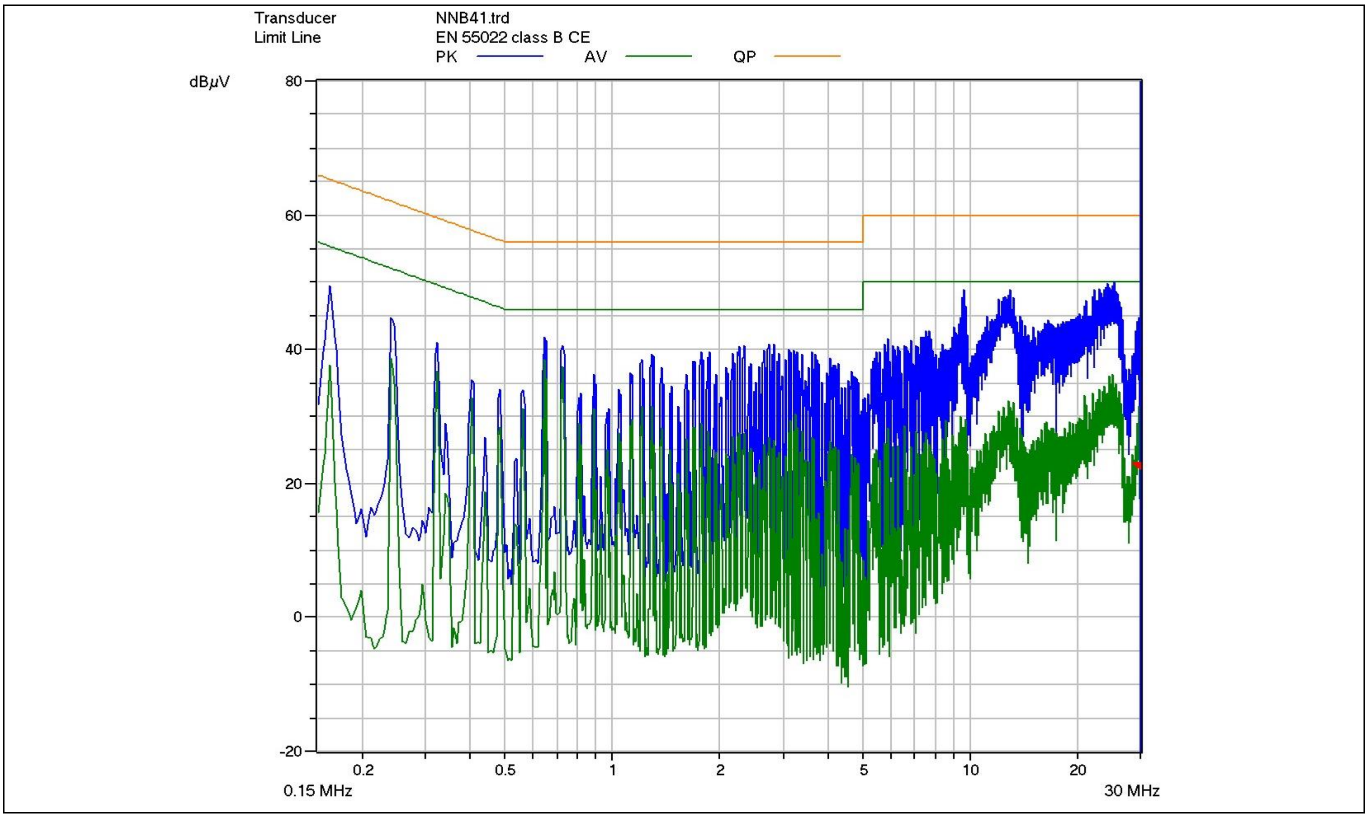


Figure 14 Conducted emissions (neutral) at 230 V AC and maximum load

Pass conducted emissions EN 55022 (CISPR 22) Class B with 6 dB margin for quasi-peak measurement at high-line (230 V AC).

10.9 Thermal measurement

The thermal test of the open-frame reference board was done using an infrared thermography camera (FLIR-T420) at an ambient temperature of 25°C. The measurements were taken after one hour running at full load condition.

Table 5 Hottest temperature of reference board

No.	Major component	85 V AC (°C)	300 V AC (°C)
1	TR1 (transformer)	60.2	69.8
2	D21 (secondary diode)	77.0	77.9
3	IC11 (ICE5QR1680BG-1)	84.5	89.2
4	L11 (choke)	85.1	39.2
5	Ambient	25.0	25.0

85 V AC full load and 25°C ambient	300 V AC full load and 25°C ambient

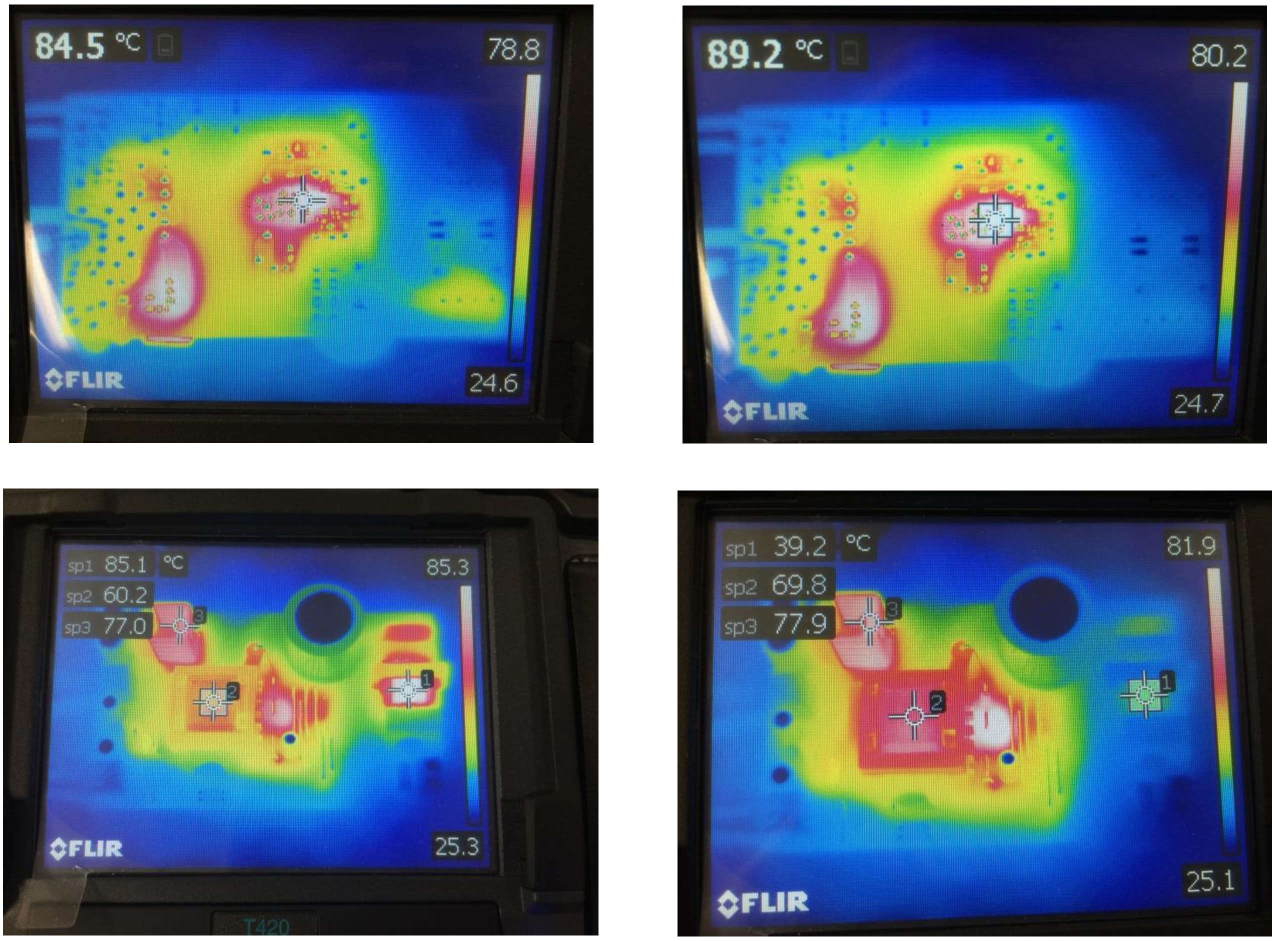


Figure 15 Infrared thermal image of REF_5QR1680BG-1_27W1

11 Waveforms and scope plots

All waveforms and scope plots were recorded with a TELEDYNELECROY 606Zi oscilloscope.

11.1 Start up at low/high AC-line input voltage with maximum load

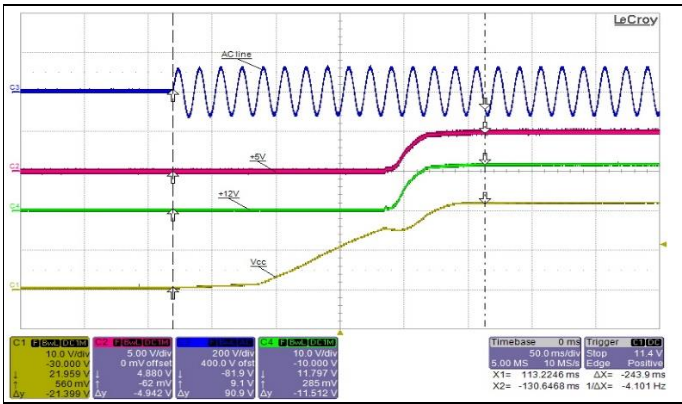
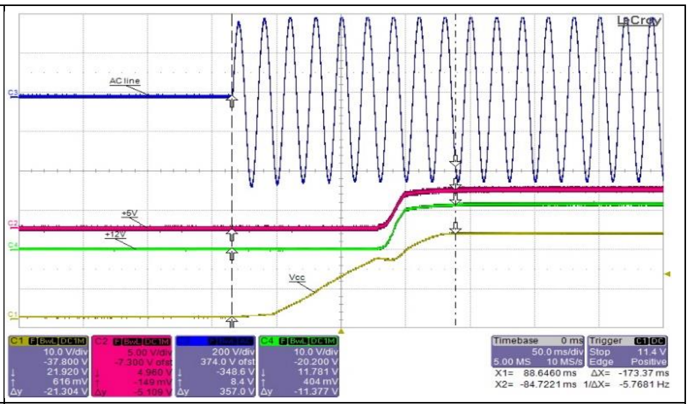
	
C1 (yellow): Supply voltage (V_{VCC}) **C2 (purple):** 5 V output voltage (V_{Out5}) **C3 (blue):** AC-line voltage (AC_V_{IN}) **C4 (green):** 12 V output voltage (V_{Out12})	**C1 (yellow):** Supply voltage (V_{VCC}) **C2 (purple):** 5 V output voltage (V_{Out5}) **C3 (blue):** AC-line voltage (AC_V_{IN}) **C4 (green):** 12 V output voltage (V_{Out12})
Startup time at 85 V AC and maximum load ≈ 244 ms	Startup time at 300 V AC and maximum load ≈ 173 ms

Figure 16 Startup

11.2 Soft start

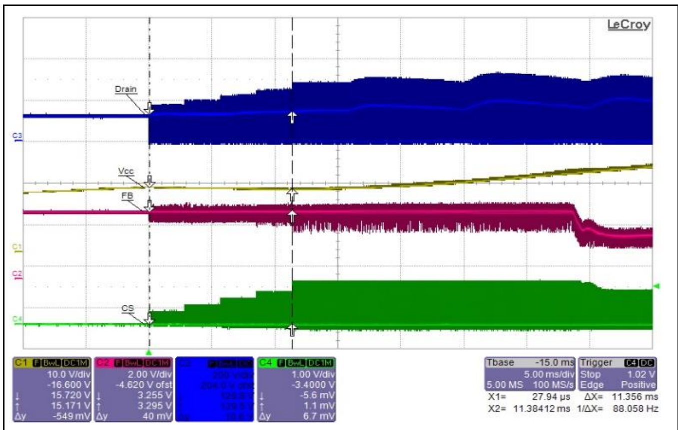
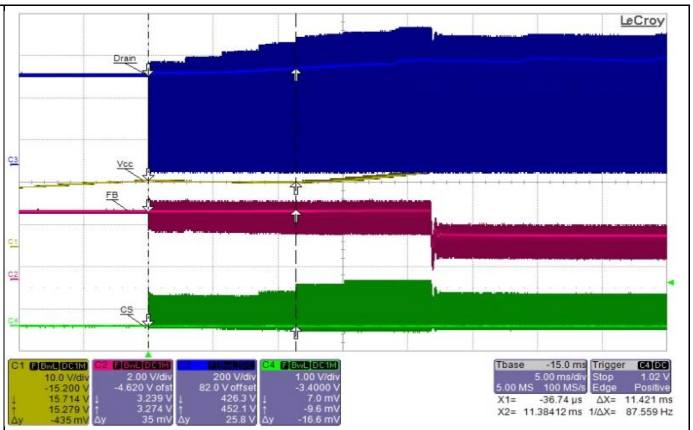
	
C1 (yellow): Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})
Soft-start time at 85 V AC and maximum load ≈ 11.3 ms	Soft-start time at 300 V AC and maximum load ≈11.4 ms

Figure 17 Soft start

11.3 Drain and CS voltage at maximum load

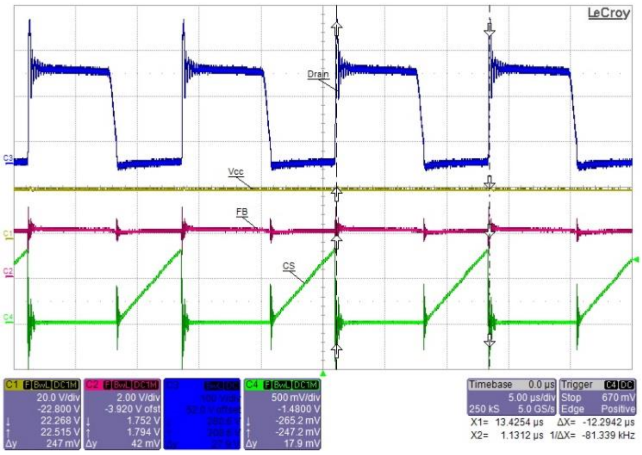
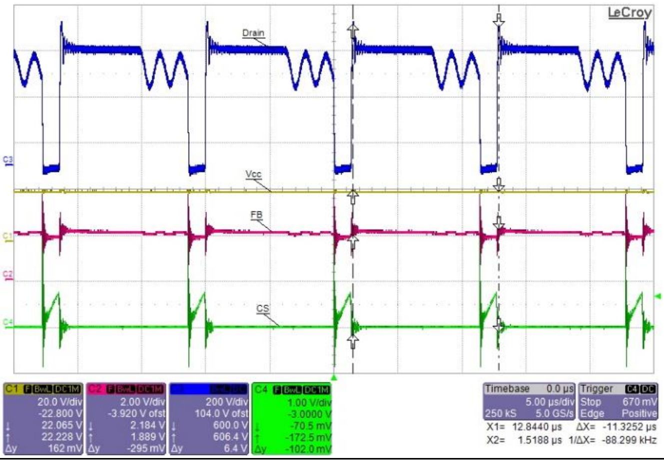
	
C1 (yellow): Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})
V_{Drain_peak} ≈ 308 V at 85 V AC with 1st ZC and f_S ≈ 81.3 kHz	V_{Drain_peak} ≈ 606 V at 300 V AC with 3rd ZC and f_S ≈ 88.3 kHz

Figure 18 Drain and CS voltage at maximum load

11.4 Zero crossing point during normal operation

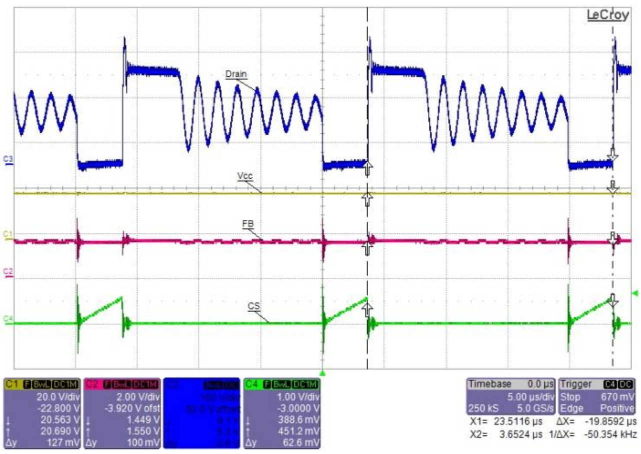
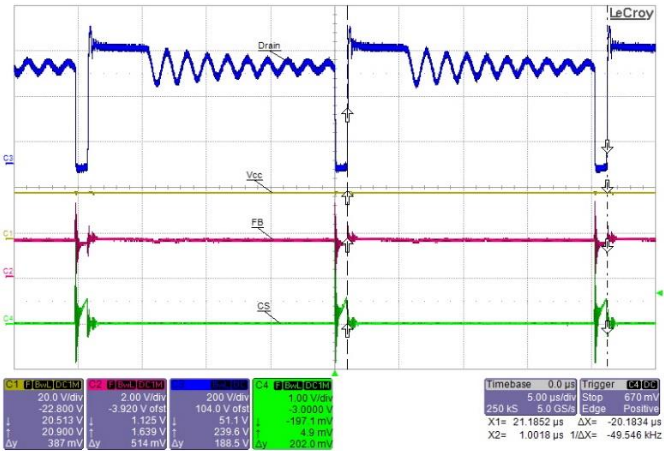
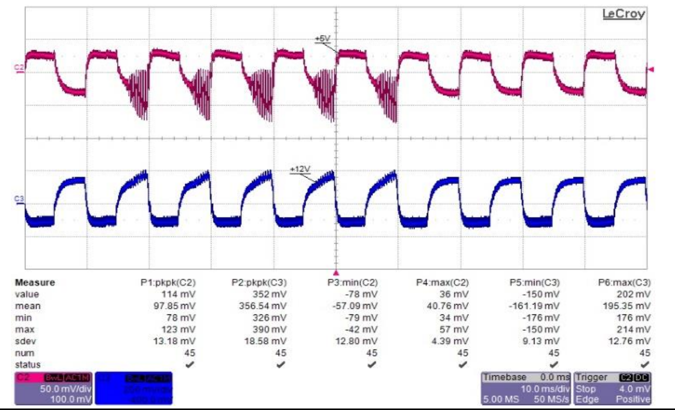
	
C1 (yellow): Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})
8th ZC at 85 V AC and 25% load (ZC varies from 1~8 for low line)	10th ZC at 300 V AC and 25% load (ZC varies from 3~10 for high line)

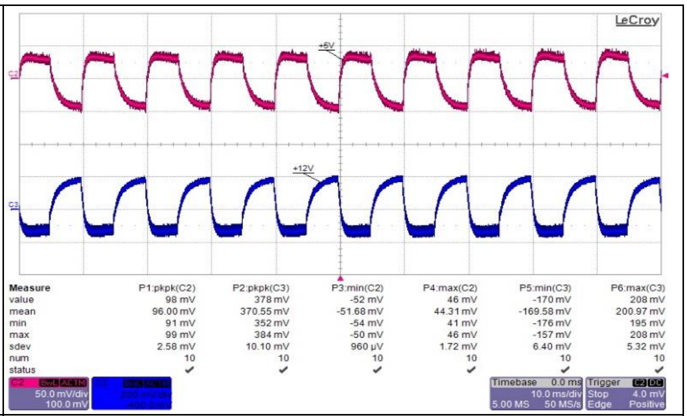
Figure 19 Zero crossing

11.5 Load transient response (dynamic load from 10% to 100%)



C2 (purple): 5 V output ripple voltage (V_{Out5})
C4 (blue): 12 V output ripple voltage (V_{Out12})

5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 114 mV
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 352 mV
(12 V load change from 10% to 100% and 5 V at 200 mA load at 85 V AC, 100 Hz, 0.4 A/µs slew rate)
Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter

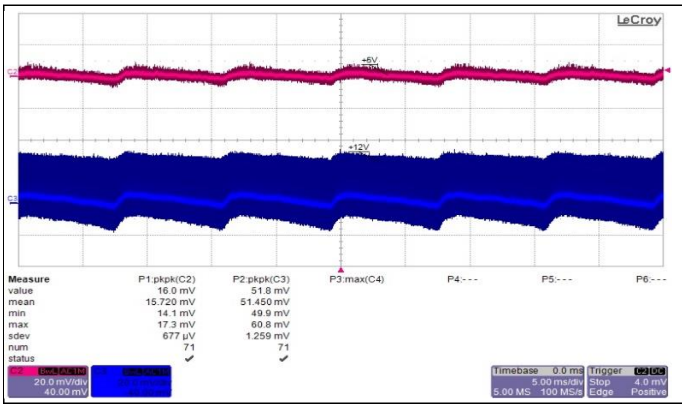


C2 (purple): 5 V output ripple voltage (V_{Out5})
C4 (blue): 12 V output ripple voltage (V_{Out12})

5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 98 mV
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 378 mV
(12 V load change from 10% to 100% and 5 V at 200 mA load at 300 V AC, 100 Hz, 0.4 A/µs slew rate)
Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz filter

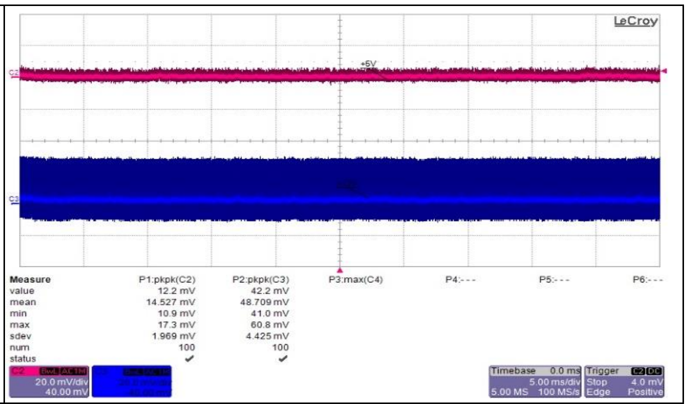
Figure 20 Load transient response

11.6 Output ripple voltage at maximum load



C2 (Purple): 5 V Output ripple voltage (V_{Out5})
C3 (Blue): 12 V Output ripple voltage (V_{Out12})

5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 16 mV
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 51.8 mV
Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (Electrolytic), 20 MHz filter

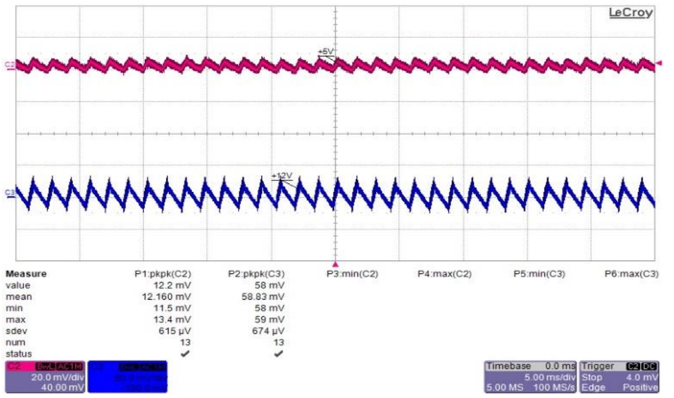


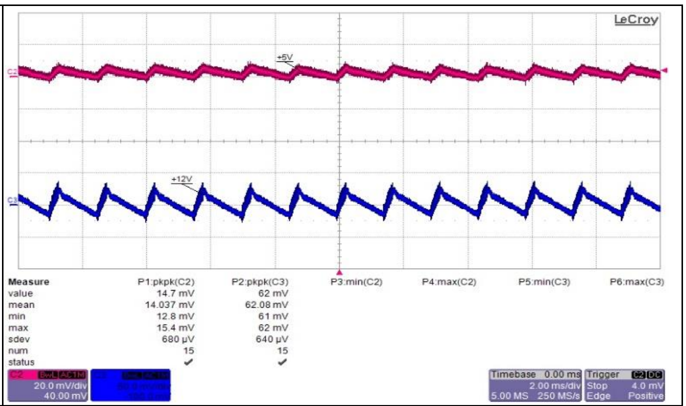
C2 (Purple): 5 V Output ripple voltage (V_{Out5})
C3 (Blue): 12 V Output ripple voltage (V_{Out12})

5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 12.2 mV
12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 42.2 mV
Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (Electrolytic), 20 MHz filter

Figure 21 Output ripple voltage at maximum load

11.7 Output ripple voltage at ABM 1 W load

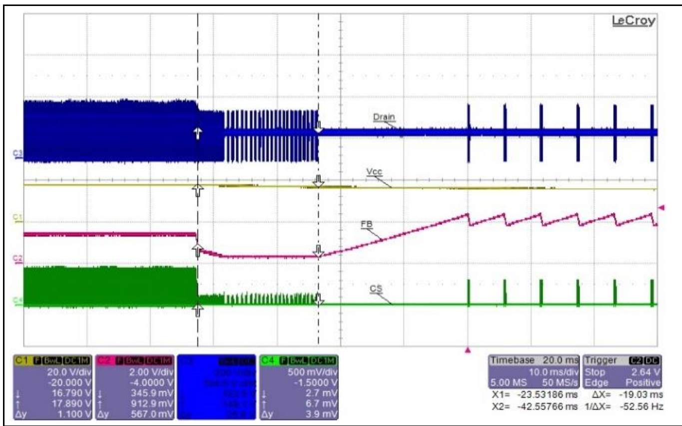


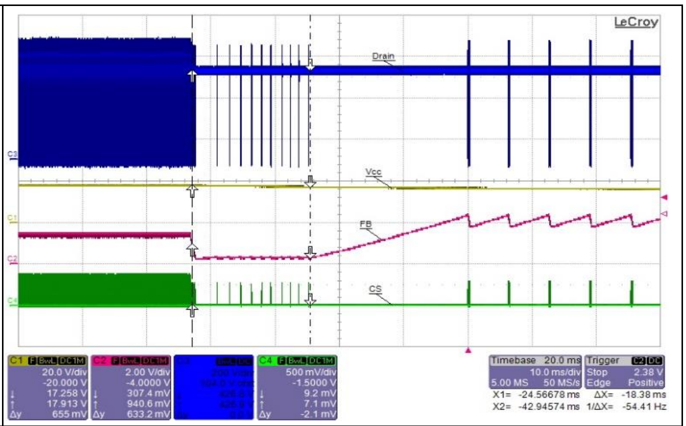


C2 (Purple): 5 V Output ripple voltage (V_{Out5}) **C3 (Blue):** 12 V Output ripple voltage (V_{Out12})	**C2 (Purple):** 5 V Output ripple voltage (V_{Out5}) **C3 (Blue):** 12 V Output ripple voltage (V_{Out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 12.2 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 58 mV **Load:** 5 V at 6 mA and 12 V at 80 mA Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (Electrolytic), 20 MHz filter	5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 14.7 mV 12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 62 mV **Load:** 5 V at 6 mA and 12 V at 80 mA Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (Electrolytic), 20 MHz filter

Figure 22 Output ripple voltage at ABM 1 W load

11.8 Entering ABM





C1 (Yellow): Supply voltage (V_{VCC}) **C2 (Purple):** Feedback voltage (V_{FB}) **C3 (Blue):** Drain voltage (V_D) **C4 (Green):** Current sense voltage (V_{CS})	**C1 (Yellow):** Supply voltage (V_{VCC}) **C2 (Purple):** Feedback voltage (V_{FB}) **C3 (Blue):** Drain voltage (V_D) **C4 (Green):** Current sense voltage (V_{CS})
Condition to enter burst mode level 1: V_{FB} < 0.9 V, N_{ZC} = 8 and $t_{blanking}$ = 20 ms (load change form 5 W to 0.5 W at 85 V AC)	**Condition to enter burst mode level 1:** V_{FB} < 0.9 V, N_{ZC} = 10 and $t_{blanking}$ = 20 ms (load change form 5 W to 0.5 W at 300 V AC)

Figure 23 Entering ABM

11.9 During ABM

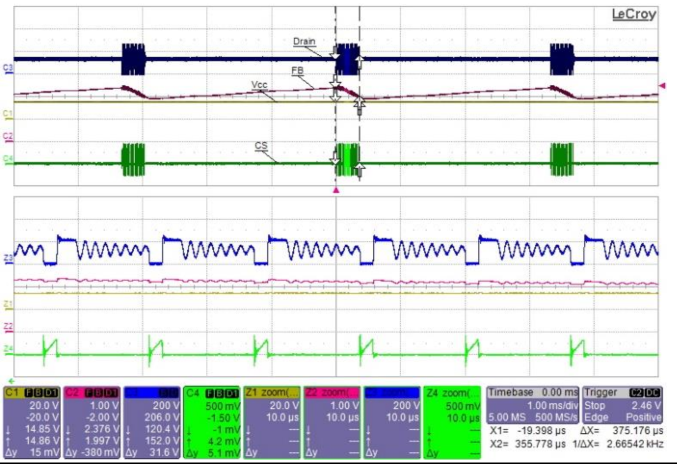
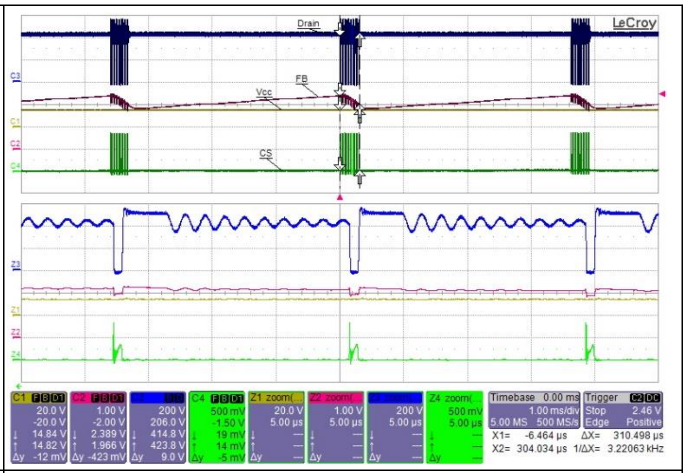
	
C1 (yellow): Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})
During ABM level 1: V_{FB_BOn} = 2.4 V, V_{FB_BOff} = 2.0 V, V_{CSBLP} = 0.31 V, N_{ZC} = 8 (0.5 W load at 85 V AC)	**During ABM level 1:** V_{FB_BOn} = 2.4 V, V_{FB_BOff} = 2.0 V, V_{CSBLP} = 0.31 V, N_{ZC} = 10 (0.5 W load at 300 V AC)

Figure 24 During ABM

11.10 Leaving ABM

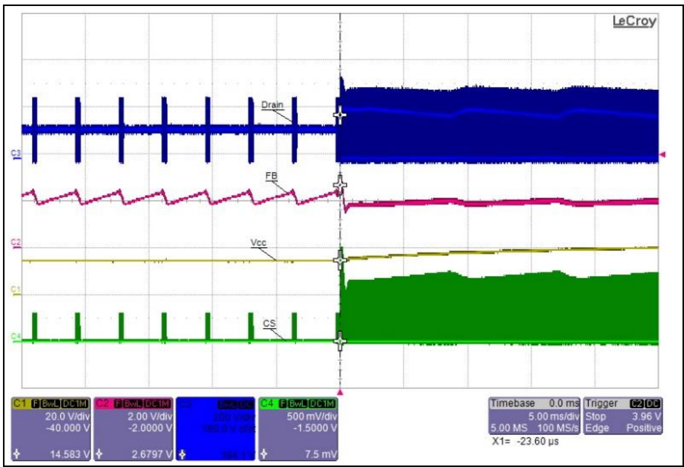
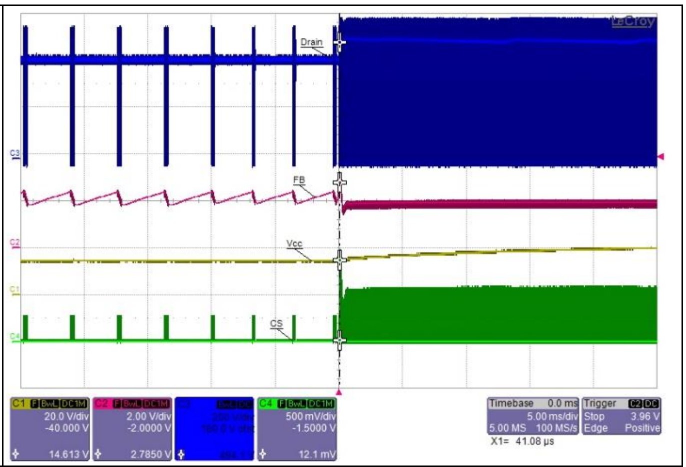
	
C1 (yellow): Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Supply voltage (V_{VCC}) **C2 (purple):** Feedback voltage (V_{FB}) **C3 (blue):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})
Condition to leave ABM level 1: V_{FB} > 2.75 V (Load change from 0.5 W to full load at 85 V AC)	**Condition to leave ABM level 1:** V_{FB} > 2.75 V (Load change from 0.5 W to full load at 300 V AC)

Figure 25 Leaving ABM

11.11 Line OVP (non-switch auto-restart)

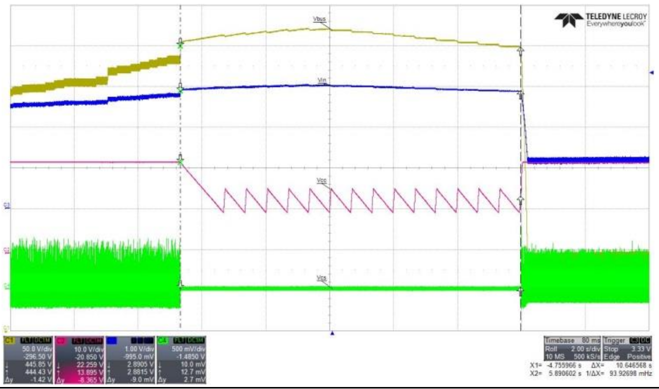
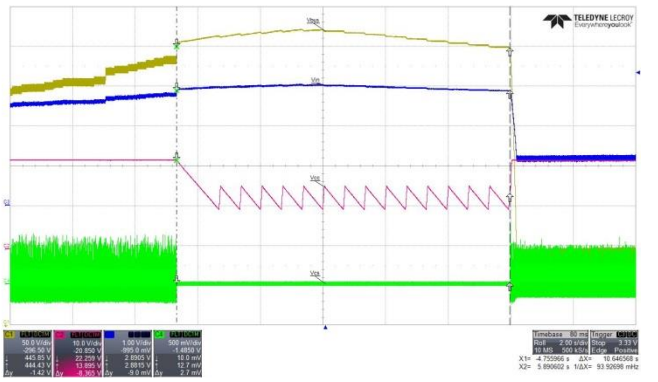
	
C1 (yellow): Bus voltage (V_{Bus}) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** V_{IN} voltage (V_{VIN}) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Bus voltage (V_{Bus}) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** V_{IN} voltage (V_{VIN}) **C4 (green):** CS voltage (V_{CS})
Condition to detect line OVP: V_{VIN} more than 2.9 V (V_{BULK} more than 445 V DC [≈ 320 V AC]) **Condition to reset line OVP:** V_{VIN} less than 2.9 V (V_{BULK} less than 445 V)	
(Gradually increase AC-line voltage at full load until line OVP detect and decrease AC-line until line OVP reset)	(Gradually increase AC-line voltage at 1 W load (ABM) until line OVP detect and decrease AC-line until line OVP reset)

Figure 26 Line OVP

11.12 Brownout protection (non-switch auto-restart)

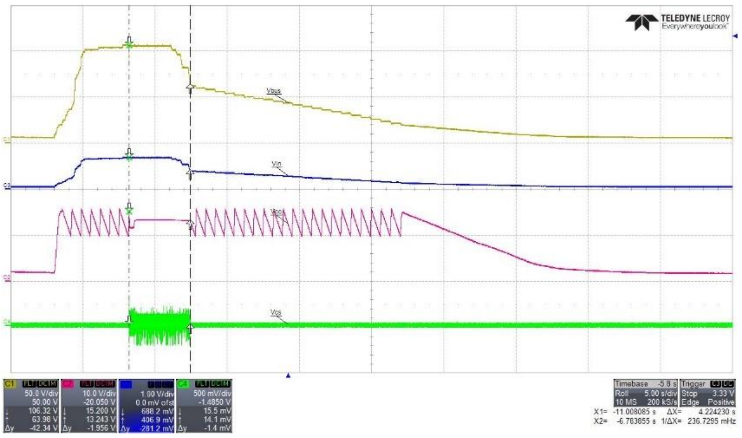
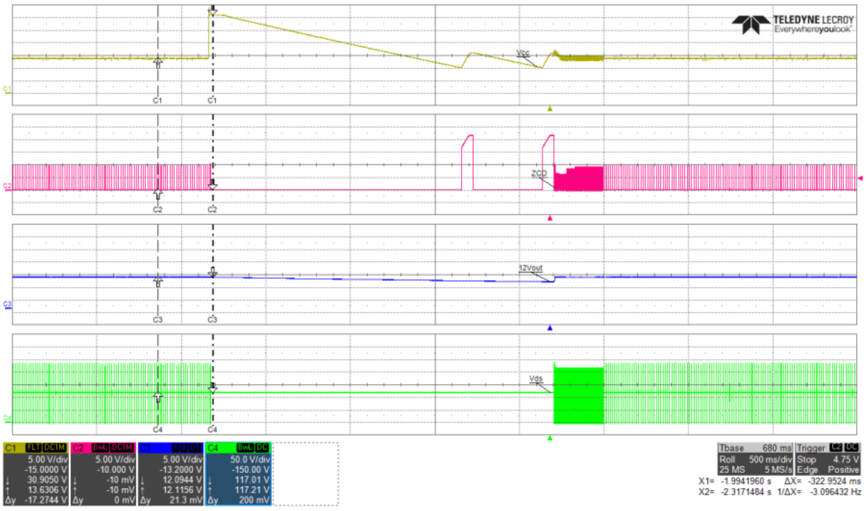

C1 (yellow): Bus voltage (V_{Bus}) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** V_{IN} voltage (V_{VIN}) **C4 (green):** CS voltage (V_{CS})
Condition to reset brownout protection (brownin): V_{VIN} more than 0.66 V (V_{BULK} more than 106 V DC [≈ 75 V AC]) **Condition to detect brownout protection:** V_{VIN} less than 0.4 V (V_{BULK} less than 63 V DC [≈ 43 V AC])
(Gradually increase AC-line voltage at 1 W (5 V at 6 mA and 12 V at 80 mA) load until system starts and reduce the line until brownout detect)

Figure 27 Brownout protection

11.13 V_{CC} OVP (odd-skip auto-restart)

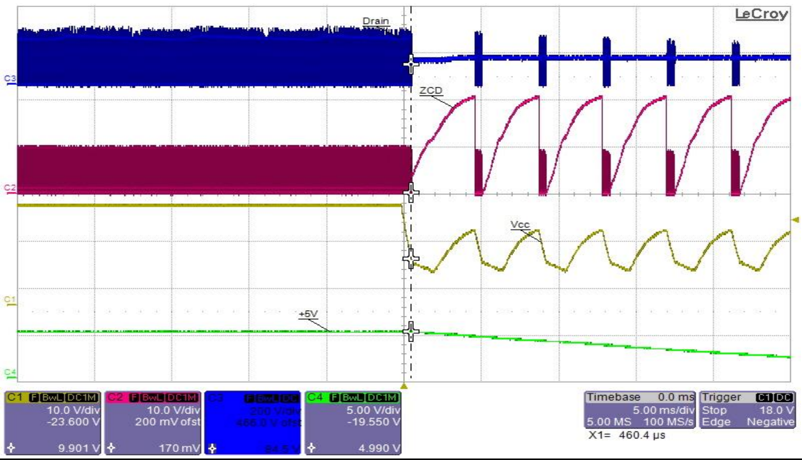


C1 (yellow): V_{CC} voltage (V_{VCC})
C2 (purple): ZCD voltage (V_{ZCD})
C3 (blue): 12 V output voltage (V_{O12})
C4 (green): VDS voltage (V_{DS})

Condition to enter V_{VCC} OVP: V_{VCC} more than 30.5 V
(at 85 V AC, no load. Apply externally a DC Pulse at V_{CC} pin > V_{VCC_OVP}.

Figure 28 V_{CC} OVP

11.14 V_{CC} undervoltage protection (auto-restart)

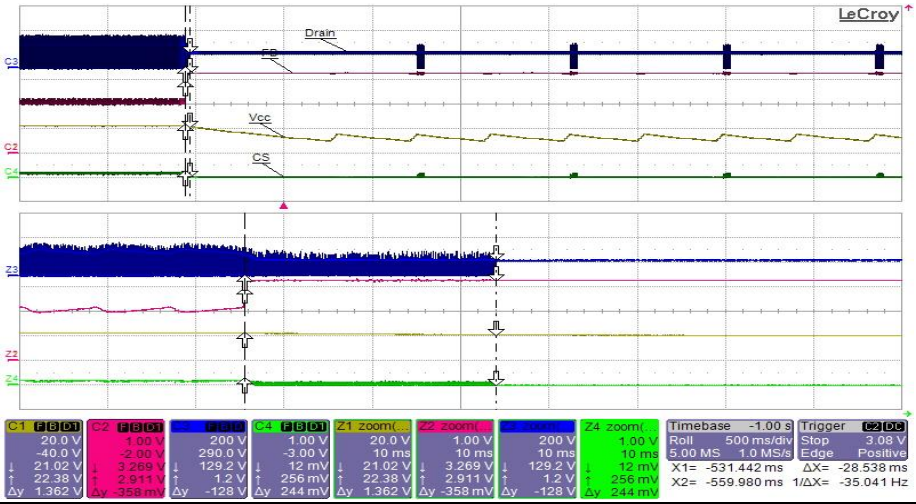


C1 (yellow): ZCD voltage (V_{ZCD})
C2 (purple): 5 V output ripple voltage (V_{Out5})
C3 (blue): Drain voltage (V_D)
C4 (green): Supply voltage (V_{VCC})

Condition to enter V_{CC} undervoltage protection: V_{CC} < 10 V
(Remove R6 during normal operation at 85 V AC)

Figure 29 V_{CC} undervoltage protection

11.15 Overload protection (odd-skip auto-restart)

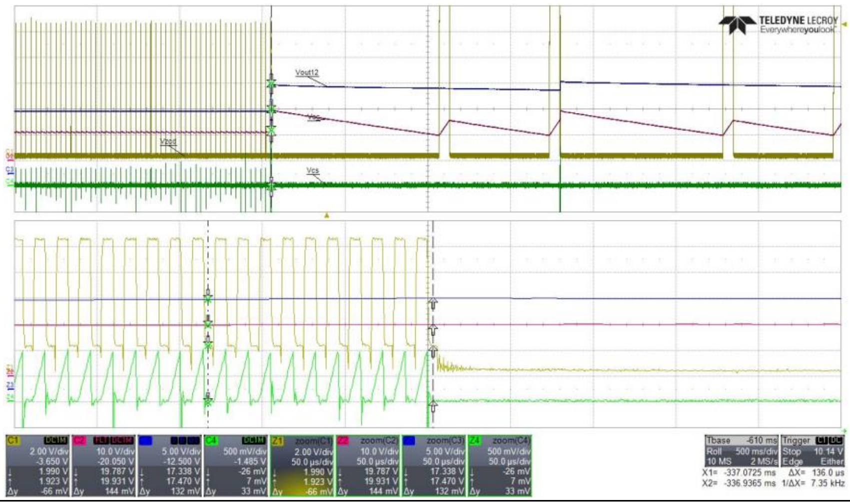


C1 (yellow): Supply voltage (V_{VCC})
C2 (purple): Feedback voltage (V_{FB})
C3 (blue): Drain voltage (V_D)
C4 (green): CS voltage (V_{CS})

Condition to enter OVP: V_{FB} > 2.75 V and lasts for 30 ms blanking time
(12 V output load change from full load to short at 85 V AC)

Figure 30 OVP

11.16 Output OVP (odd-skip auto-restart)

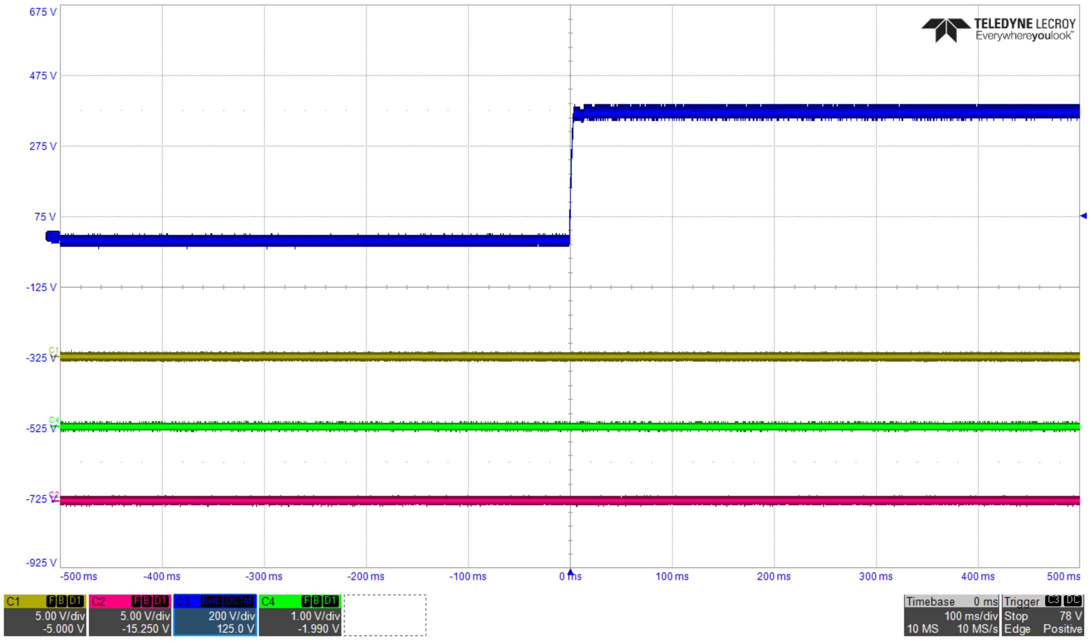


C1 (yellow): ZCD voltage (V_{ZCD})
C2 (purple): Supply voltage (V_{VCC})
C3 (blue): 12 V output voltage (V_{O12})
C4 (green): CS voltage (V_{CS})

Condition to enter output OVP: V_{ZCD} more than 1.9 V
(85 V AC, short R26 during system operation at no load)

Figure 31 Output OVP

11.17 V_{CC} short-to-GND protection



C1 (yellow): V_{CC} voltage (V_{VCC})
C2 (purple): Feedback voltage (V_{FB})
C3 (blue): Drain voltage (V_D)
C4 (green): CS voltage (V_{CS})

Condition to enter V_{CC} short-to-GND: if $V_{CC} < V_{VCC\_SCP}$ $I_{VCC} = I_{VCC\_Charge1}$
(Short V_{CC} pin to GND and measure the input current, I_{in} ≈ 23.4 mA and input power is ≈ 36 mW at 264 V AC)

Figure 32 V_{CC} **short-to-GND protection**

References

[1] Infineon Technologies AG: *ICE5QRxx80BG-1 datasheet*; Available online

[2] Infineon Technologies AG: *CoolSET™ 5th Generation Quasi-Resonant Plus flyback design guide;* Available online

[3] Infineon Technologies AG: *CoolSET™ 5th Generation Quasi-Resonant Plus calculation tool for flyback*; Available online

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Revision history

Document revision	Date	Description of changes
V 1.0	2024-11-19	Initial release

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